Geotechnical Engineering Education 2020

GEE 2020

Editors:

Marina Pantazidou, *National Technical University of Athens, Greece*

Michele Calvello, *University of Salerno, Italy*

Margarida Pinho Lopes, *University of Aveiro, Portugal*

Proceedings of the 5th International Conference on Geotechnical Engineering Education, Athens, Greece, June 23-25, 2020

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Preface

The international conference on Geotechnical Engineering Education, GEE 2020, was organized by the technical committee TC306 of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) under the auspices of the School of Civil Engineering of the National Technical University of Athens, the Hellenic and the International Societies for Soil Mechanics and Geotechnical Engineering, and the City of Athens. It was an online conference, streamed on June 23-25, 2020.

The conference brought together education researchers and geotechnical engineering professors, researchers and practitioners. The conference was designed to serve as a blueprint for a discipline to organize its own education and create education funded projects, in addition to disseminate scholarly practices and research results. Specific objectives included the following:

1) to promote adoption of results from research on education in engineering instruction;

2) to disseminate educational collaborations between engineering schools and engineering consulting firms;

3) to sponsor the training of young engineering academics in evidenced-based practices for effective teaching;

4) to stimulate future activities and collaborations in support of geotechnical engineering education, with the help of two panel discussions on “Geo-engineering education papers: scope, characteristics and use” (Panel 1) and “Building a community of scholarly education practice” (Panel 2), which are available at TC306’s YouTube channel.

In addition to typical education theme topics, such as Curricula, Coursework, Open Resource Educational Material and Links to Research on Learning and on Engineering Education, GEE 2020 had two priority themes: “Training for Geotechnical Engineering Instructors” (Priority Theme 1) and “Incentives and Opportunities for Industry-Academia Collaboration” (Priority Theme 2). Unfortunately, Priority Theme 1 was not represented with any paper; this lack was partly offset by the discussion in Panel 2 and by awarding a competitive prize to a young geotechnical engineering educator to attend a conference on engineering education.

These proceedings are mostly a record of what the conference leaves behind. As to the future directions, discussions pointed to the need for a) including the Critical State Soil Mechanics Framework in undergraduate instruction, b) compiling a collection of open access images and graphs, c) creating a repository of peer-reviewed educational material and d) developing refresher courses for geotechnical instructors with the broader aim to revitalize geotechnical engineering teaching.

Marina Pantazidou
Michele Calvello
Margarida Pinho Lopes

July 2020

Organization

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2nd John Burland Honor Lecture

Reflections on Some Contemporary Aspects of Geotechnical Engineering Education – From Critical State to Virtual Immersion

M. B. Jaksa

University of Adelaide, Adelaide, Australia
mark.jaksa@adelaide.edu.au

ABSTRACT: This paper documents the 2nd Burland Lecture on Geotechnical Engineering Education. The paper explores three contemporary aspects of geotechnical engineering education. Firstly, critical state soil mechanics, which was developed around 60 years ago, is re-examined and a case is made for incorporating it into mainstream, undergraduate civil engineering education. Online learning, in particular, the flipped classroom, is then discussed briefly. Finally, the emerging technology of immersive learning is explored from the lens of geotechnical engineering education.

Keywords: Critical state soil mechanics, Flipped classroom, Interactive learning modules, Online learning, Immersive technologies

1 Introduction

It is indeed a great honour to have been selected by peers and colleagues from TC306 – the technical committee of the International Society of Soil Mechanics and Geotechnical Engineering which focuses on geo-engineering education – to deliver the 2nd John Burland Lecture on geotechnical engineering education. It is also an immense privilege to follow in the footsteps of the presenter of the 1st John Burland Lecture, Prof. John Atkinson. Both Johns are, without doubt, giants in the field of geotechnical engineering, not only in education, but also in research and practice. Both are heroes of mine and I am indeed humbled to be in such esteemed company.

In this paper, as you will see, I draw inspiration from both Johns. As John Atkinson stated in his 1st Burland Lecture, the focus was on what to teach, rather than the process, in other words, how to teach. John's 1st John Burland Lecture provided great insights in 'what' to teach in geotechnical engineering. Most of my work, in the geotechnical engineering education space, has focussed on 'how' best to teach geotechnical engineering. However, in this paper, whilst most of my attention will be directed to the 'how to teach' paradigm, I will also devote some effort to one aspect of 'what to teach'; that is, on the topic of incorporating critical state soil mechanics in geotechnical engineering curricula.

In this paper, I will examine three topics. First, I'll look backwards in time and (hopefully) present a cogent and compelling case for why critical state soil mechanics is relevant today in the undergraduate curriculum of civil engineers. I will then look to the present time and spend a few moments discussing a pedagogy known as flipped learning which is significantly disrupting higher education. Finally, I'll peer a little forward into the future and explore a technology that also has the potential to benefit geotechnical engineering education; namely immersive technologies.

2 Critical State Soil Mechanics

I'd like to start by exploring the question: "Is there a place for the teaching of critical state soil mechanics in the undergraduate curriculum of civil engineers?" My firm belief to this question is in the affirmative. I'll first begin with an overview of critical state soil mechanics. I'll then explore the views of others, who speak for and against this question. Finally, I will make my own case in favour of the proposition.

Critical state soil mechanics (CSSM) is a soil mechanics framework that coalesced in the 1950s and 1960s, largely as a result of the work of Kenneth Roscoe, Andrew Schofield, Peter Wroth and John Burland from Cambridge University (Roscoe et al., 1958; Schofield & Wroth, 1968). As Jefferies (2019) noted, CSSM was greatly informed by the work of researchers at Imperial College (e.g. Bishop, Cornforth, Gibson, Henkel and Parry), as well as individuals from the US Corps of Engineers, Harvard and MIT, most notably Donald Taylor (Baecher & Christian, 2015). Since then, CSSM has been widely adopted in research, but much less so in undergraduate education and practice.

At its core, CSSM links load, shearing and volume change, as shown graphically in Figure 1. It unifies fine- and coarse-grained soils, drained and undrained loading, and, in the case of fine-grained soil, normally consolidated and overconsolidated soils, and in the case of coarse-grained soils, loose and dense soils; all within a single framework. Anyone who has studied Schofield & Wroth (1968) and Wood (1990) will realise that, whilst being extremely powerful, CSSM is also complex and requires mathematical skills often beyond those of many undergraduate students. It is likely that the complex, theoretical nature of CSSM, as well as the fact that it is underpinned by artificial, rather than natural, undisturbed soils, has alienated CSSM from many in practice and academia.

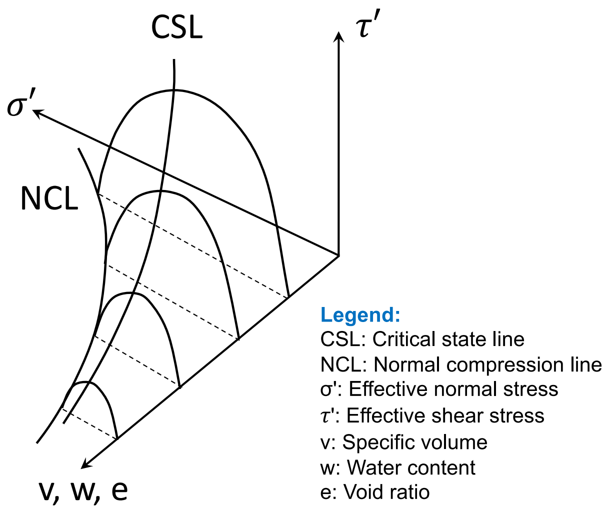

Figure 1. Graphical representation of CSSM – the state boundary surface for soil, adapted from Atkinson (2014)

John Atkinson has done much to demystify CSSM and make it readily accessible to undergraduate students and practitioners, particularly in three of his textbooks: Atkinson & Bransby (1978) and Atkinson (2007, 2014). As Atkinson stated in the preface to the first edition of his elegant textbook *An Introduction to the Mechanics of Soils and Foundations Through Critical State Soil Mechanics* (Atkinson, 1993):

> “The term ‘critical state soil mechanics’ means different things to different people. Some take critical state soil mechanics to include the complete mathematical model known as Cam Clay and they would say that this is too advanced for an undergraduate course. My view is much simpler, and by critical state soil mechanics I mean the combination of shear stress, normal stress and volume into a single unifying framework. In this way a much clearer idea emerges of the behaviour of normally consolidated and overconsolidated soils during drained and undrained loading up to, and including, the ultimate or critical states. It is the relationship between the initial states and the critical states that largely determines soil behaviour. This simple framework is extremely useful for teaching and learning about soil mechanics and it leads to a number of simple analyses for stability of slopes, walls and foundations.”

Airey and Miao (2016) similarly argue that CSSM should be taught to all civil engineering undergraduate students:

> “…the critical state framework underlies our current understanding of soil behaviour. It therefore makes sense to teach the simple critical state framework to introduce students to the important aspects of soil behaviour. The model is able to explain key aspects of soil behaviour and allows a broad understanding of ground behaviour. At the same time, it should be emphasised that this

> is an idealised model and that detailed geotechnical design will require more sophisticated approaches."

However, one merely needs to look at Wikipedia to observe that several in the geotechnical engineering community are not enamoured with CSSM. Furthermore, some strongly oppose the inclusion of CSSM in undergraduate curricula. For example, Wesley (2015) stated:

> "Teaching material that has little or no relevance to practical engineering, such as critical state soil mechanics, should find no place in undergraduate courses."

Jefferies (2019) argues that the reluctance of many academics who have consciously chosen not to teach CSSM, is likely due to the limitations of the original Cam Clay model (circa 1975), which "does not remotely capture the behaviour of soils denser than their CSL [critical state line], which is most soils that you will encounter in practice". Furthermore, he posits that the Cam Clay model was based on "an unnecessary assumption, and with that assumption corrected by the state parameter [see §2.2], CSSM becomes applicable to all soils, all densities, and all loading paths."

From my perspective, Atkinson (1993; 2007) and Airey and Miao (2016) make a compelling case for the inclusion of CSSM in the teaching of undergraduate civil engineering students. They demonstrate that CSSM uniquely unifies the strength, compressibility, density and moisture content of soils, for both fine- and coarse-grained, into a single, unifying theoretical framework. It is incredibly powerful to help explain to students key aspects of soil behaviour, such as soil compressibility, friction and volume change due to shearing (critical state line); the importance of stress path (drained/undrained strengths); and apparent cohesion (Airey & Miao, 2016).

As stated by Airey and Miao (2016), if CSSM is taught in undergraduate curricula, it is often as an afterthought, adding to the students' bewilderment in relation to their understanding of soil behaviour. Atkinson (2007) provides a universal framework for the inclusion of CSSM in geotechnical engineering instruction and Airey and Miao (2016) provide further examples of how educators might implement CSSM in their teaching.

Rather than adopting the common 'siloed' approach to the teaching of soil mechanics, where topics such as soil strength, compressibility, compaction and seepage are often taught in an isolated and disconnected fashion, it is recommended that a more holistic approach be adopted, which includes significant elements from CSSM. It is suggested, for example, that very early on in their instruction of soil mechanics, students might be asked to sketch a series of graphs, with respect to a fine-grained soil, that express the relationships between: soil strength and confining pressure; soil strength and water content and density; and soil compressibility and water content and density. Students beginning their geotechnical engineering education intuitively know that loose soil is weaker and settles more than dense or dry soil. It is not difficult to guide students to postulate on and create a three-dimensional representation of strength, deformation and water content or density, as shown previously in Figure 1.

At this point, I would like to present two, from my perspective extremely important, additional reasons for adopting CSSM in the teaching of soil mechanics to undergraduate geotechnical engineering students; namely, unsaturated soils and liquefaction.

2.1 Unsaturated Soils

Modern experimental studies relating to the shearing of unsaturated soils date back to the 1950s and '60s (Lu & Likos, 2004). Since then, two models have emerged: the *effective stress approach*, which is based on Bishop (1959) and summarised in (1); and the *independent stress state approach*, which is based on Fredlund & Morgenstern (1977) and is summarised in (2).

$$\tau_f = c' + \left[(\sigma - u_a)_f + \chi_f (u_a - u_w)_f\right] \tan\phi' \qquad (1)$$

$$\tau_f = c' + (\sigma - u_a)_f \tan\phi' + (u_a - u_w)_f \tan\phi^b \qquad (2)$$

where: τ_f is the shear stress at failure; c' is the effective cohesion; $(\sigma - u_a)_f$ is the net normal stress at failure; u_a is the pore air pressure; χ_f is the effective stress parameter; $(u_a - u_w)_f$ is the matric suction at failure; u_w is the pore water pressure; ϕ' is the internal angle of friction; and ϕ^b is the internal angle of friction associated with matric suction.

Largely due to difficulties in explaining the observed collapse upon inundation of unsaturated soils and the perceived lack of a unique relationship between χ and the degree of saturation (Khalili et al., 2004), the effective stress approach fell out of favour. However, largely due to the work of Khalili (Khalili & Khabbaz, 1998; Loret & Khalili, 2002; Khalili et al. 2004), the effective stress approach has been revived and has since gained broader acceptance within the unsaturated soil mechanics community.

A key strength of the effective stress approach is that, through CSSM, it is able reliably to predict strength and volumetric change in unsaturated soils. By analysing many tests performed on unsaturated soils, Khalili et al. (2004) concluded:

> “that the critical state line is unique in the deviatoric stress-effective mean stress plane for both saturated and unsaturated states of a soil. This has a significant simplifying effect on the constitutive modelling of unsaturated soils.”

Hence, CSSM works for both saturated and unsaturated soils.

2.2 Liquefaction

In his keynote paper at the 13th Australia New Zealand Conference on Geomechanics in Perth, Jefferies (2019) stated that the origins of CSSM “lie in the very practical concern of avoiding dam failures caused by liquefaction.” He went on to stress:

> “Today, CSSM (in the wider sense, there being various models within the framework) is the basis of modern understanding of soil behaviour and [is] becoming accessible to practicing engineers through geotechnical software. But why has it taken 50 years? And why is this paper even a keynote, with the implication that CSSM is new to so many engineers?”

In their textbook *Soil Liquefaction – A Critical State Approach*, Jefferies & Bean (2006) state:

> “In summary, a critical state view and associated generalised constitutive model (NorSand) provides a simple computable model that captures the salient aspects of liquefaction in all its forms. This critical state view is easy to understand, is characterised by a simple state parameter (ψ) with a few material properties (which can be determined on reconstituted samples), and lends itself to all soils.”

Finally, in the words of Barnes (2016):

> “[CSSM] assumes that soils behave in an ideal manner, that they have isotropic structures and stress conditions, they are homogeneous throughout their mass and that they have no preferred structure within them, i.e. they are remoulded or reconstituted soils.
>
> Real soils in the ground do not behave in an ideal manner, they have anisotropic structures due to preferred particle orientations of the grains, they are subjected to anisotropic stress conditions and are usually non-homogeneous due to fabric effects such as layering and fissuring. As well as the fabric effects, in situ soils have often developed some interparticle bonding which would be destroyed on remoulding and this is not included in the theories.
>
> Nevertheless, the concepts of a state boundary surface, a critical state condition, the inter-relationships between mean stress, deviator stress and volume, the effects of drainage conditions, elastic and plastic straining, yielding and hardening provide a sound framework for the understanding of basic soil behaviour.”

The research undertaken on unsaturated soils and liquefaction, however, demonstrate that CSSM **is** valuable in representing **real** soils. As such, I hope that I might have been able to present a compelling case that there is great educational merit in including CSSM in the undergraduate curriculum of civil engineers. If not, then perhaps to, at least, consider it and explore it further.

3 Flipped Learning

It is particularly pertinent at this time, when the world, and this conference, has been significantly impacted by the COVID-19 pandemic, to reflect briefly on online modes of learning. Here, I’d like to revisit a topic that I discussed back in 2012 at the *Shaking the Foundations of Geotechnical Engineering Education Conference* (SFGE) in Galway, Ireland. There, I presented the concept of interactive learning modules (ILMs) (Jaksa 2012), as well as an example of how they might be implemented in the context of geotechnical engineering laboratory classes (Jaksa et al., 2012). At that time, the associated pedagogy was known as just-in-time-teaching, but since then it has become more widely referred to as *flipped learning*.

As higher education has moved in recent times to a greater emphasis on mass education (Jaksa et al., 2009) class sizes have inevitably grown. As a result, traditional models of university instruction have been questioned. This has been exacerbated by the fact that, at the same time, technological advances – such as the internet, mobile devices and accessible video recording facilities – have transformed higher education. This led to the flipped learning pedagogy, which grew out of Salman Khan's revolutionary development of short, online instructional videos (TED, 2011) and augmented by just-in-time-teaching (Prince & Felder, 2007). AdvanceHE (2018), defined flipped learning as:

> "A pedagogical approach in which the conventional notion of classroom-based learning is inverted, so that students are introduced to the learning material before class, with classroom time then being used to deepen understanding through discussion with peers and problem-solving activities facilitated by teachers."

In other words, flipped learning is where students watch lectures at home (or elsewhere) and subsequently do their 'homework' at university, as illustrated in Figure 2.

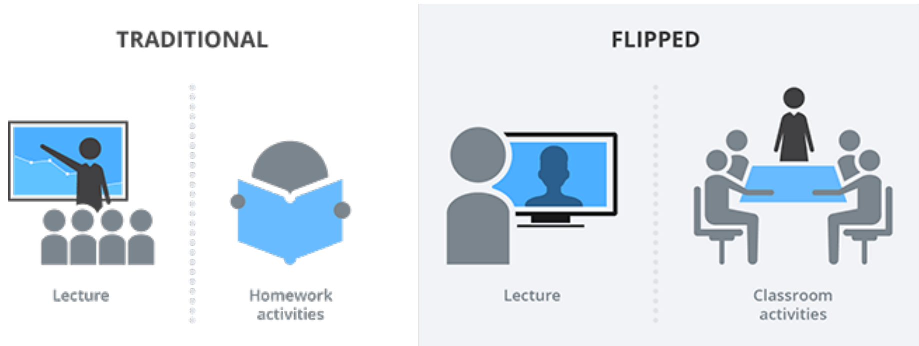

Figure 2. Schematic of flipped learning. Source: www.epiphan.com

Over the last five years or so, in Australian universities, and I suspect in many universities around the world, lectures have been automatically recorded and uploaded to their institutions' learning management systems, so that students can view them remotely. In my university, recording is automatic and mandatory in lecture theatres equipped with the relevant technology, and in my institution, this refers to the vast majority of teaching rooms. There are several advantages to such online learning. For example, students who may have missed a lecture because of illness, a timetable clash or work commitments, can view the lecture at a time that is more suitable to them. Additionally, students who live more remotely and find it challenging to travel to campus, can access the lectures more conveniently. The vast majority of students prefer this option, whereas, in my experience, the greater proportion of academics loathe it. Why? Because lecture attendance has dropped dramatically, in some cases by more than 80%, because the students overwhelmingly prefer it, and they're voting with their feet. Such students will also often speed-up the video by 1.5- or 2-times, so that they can view it more rapidly. On the other hand, some students much prefer face-to-face lectures, and they're the ones who come. It is, however, a fact that the vast majority do not sit in this camp and watch lectures asynchronously and remotely.

What are we, as academics to do about this? One can bemoan the reduction in lecture attendance, and the changing nature of higher education, or one can embrace it and adapt our pedagogies to suit. For example, some academics adopt 'participation marks' to force students to attend face-to-face lectures. I, personally, do not subscribe to this approach; I much prefer a 'carrot' to a 'stick.' If one has to coerce students to attend a lecture, what does that say about the quality of the instruction?

Emeritus Professor Rich Felder, a leading US engineering educator, who delivered a keynote lecture at the SFGE Conference in Galway in 2012, in his learning and teaching workshops, provokes attendees by asking "If you arrived one morning to deliver your lecture and there were no (or very few) students in the room, would you deliver it the same way?" At the heart of Felder's approach is active learning, which he defines as (Felder & Brent, 2009):

> "Active learning is anything course-related that all students in a class session are called upon to do other than simply watching, listening and taking notes."

Felder provides a rich (pun unintended) set of extremely helpful, practical and accessible learning and teaching resources at his Legacy Website: https://www.engr.ncsu.edu/stem-resources/legacy-site/.

Higher education, and society in general, has benefitted greatly by the move towards online learning. This is especially evident in the present circumstances of the pandemic, where students and teachers are respectively learning and instructing from home. Recently, many of us will have taught students remotely (in my case from home) using a videoconferencing facility, such as Zoom, Skype, WebEx or Microsoft Teams. These are not perfect; they don't replace face-to-face, but they've certainly been helpful. They're much better than nothing. It is almost a given, that some of the learning and teaching practices that have been adopted during the pandemic will remain with us for a very long time, if not indefinitely.

If your institution has yet to mandate recording of lectures, may I respectfully suggest that you prepare for this eventuality. Online learning is advancing rapidly, and COVID-19 has simply accelerated its pace. The traditional, didactic pedagogy, which is the norm in higher education throughout the world, was initiated when universities sprang into life 800 or so years ago. Little has changed since then (Felder 2006), except for the dramatic rise in class sizes, the accessibility of society to universities, and the availability of technologies that can be adapted to teaching and learning. Flipped learning provides a useful and logical pedagogy for blending online delivery with face-to-face learning. In my view, we as academics are at our best, as is student learning, when the classes are small, and the teachers can address each student's individual learning challenges. Flipped learning helps to facilitate this.

4 Immersive Technologies

In this section, I'd like to discuss two new technologies – 360-degree cameras and virtual reality – which provide relatively authentic immersive experiences that can aid in education. Here I'll discuss opportunities for these technologies in the geotechnical engineering context.

4.1 360-degree Cameras

Recently, the price of 360-degree cameras and their associated goggles have fallen dramatically. An example, from Kaiser Baas, is shown in Figure 3. At the time of writing, the cost of the camera is less than $US70 and the cost of the goggles is less than $US20.

What are 360-degree cameras and what do they do? A 360-degree camera is one that enables the user to capture a field of view of an entire sphere. It does so by incorporating two half-spherical lenses, one on the front and another on the back of the camera. When stitched together in a relatively simple fashion, using low-cost software and with the aid of goggles, one can visualise an environment in a relatively basic form of virtual reality. The goggles (also shown in Figure 3) enable the user to slide their mobile phone, in landscape mode, into the front plate. Using an app on the phone, two video images are displayed, one for each eye. When the goggles are worn on the user's head, by means of the mobile

Figure 3. Example of a 360-degree camera and associated goggles. Source: www.kaiserbaas.com

phone's in-built accelerometers, an almost complete sphere-of-view is observable, simply by moving one's head. Alternatively, one can watch a 360-degree video on a traditional computer screen and navigate using a mouse.

At the University of Adelaide, 360-degree cameras have been used to provide students with virtual site visits to various civil engineering construction activities. Whilst, clearly not as ideal as an actual physical site visit, these virtual visits provide several advantages. For example, over time, a catalogue of site visits can be developed, giving students a wide range of learning experiences. They permit students to visit sites, when they might otherwise have missed the opportunity to attend an actual visit because of illness or some other unforeseen event, such as last-minute, on-site challenges or inclement weather. It also facilitates distance learning.

As the videos can also incorporate sound, by means of the mobile phone's speaker or headphone jack, narration can be provided to augment the learning experience.

In geotechnical engineering, such technology can be used to observe various aspects of site investigations, such as borehole drilling, soil sampling and in situ testing. Students could also visit virtual sites in order to explore various surface features, such as topography, drainage and previous activities that might be useful in characterising a site. Students could also visit various projects, either in construction (e.g. retaining walls, foundations or pavements) or during operation (e.g. Leaning Tower of Pisa, dams, or the after-effects of an earthquake or landslide), in order more accurately to appreciate and learn from these geotechnical engineering topics.

The goggles described above permit three degrees of freedom, i.e. rotation in the three, orthogonal axes (pitch, yaw and roll). They do not, however, permit the user to translate, i.e. move horizontally or vertically. As we'll see in the next section, true virtual reality achieves this.

4.2 Virtual Reality

The Meriam-Webster Dictionary defines virtual reality (VR) as:

> "An artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment."

Very recently, VR technology has become much more accessible and affordable to educators. In mid-2019, the Facebook-owned VR technology company, Oculus VR, released a new headset, the Quest (Figure 4), which marked a step change in VR. Up until that point, because of their significant computational demands, VR headsets, such as the Oculus Rift (Figure 5) and HTC Vive, needed to be connected to a high-end graphics computer via cables and used additional, external sensors, which significantly limited the accessibility and functionality of VR. The Quest headset, on the other hand, is equipped with mobile phone type technology, and while the resolution of the image in the headset is not as sharp as previous tethered models, it is cable-free, the sensors are incorporated into the headset, and high-end computing is no longer required, as the software and processing is undertaken within the

Figure 4. Oculus Quest VR headset and hand controllers. Source: www.oculus.com/quest

Figure 5. Oculus Rift VR system. Source: www.vrzone.com

headset itself. Like similar VR equipment, the Quest enables 6-degrees of freedom; i.e. rotation in the three, orthogonal axes (pitch, yaw and roll), as well as lateral movement in the three, orthogonal axes (left-right, forward-back and up-down).

With the release of the Quest, there is now great opportunity to exploit VR technology and adapt it to a wide range of applications, including geotechnical engineering. In this section, I'd like to share, briefly, my initial thoughts and forays into this space.

In 2019, I and a group of four, final year civil engineering Honours students 'dipped our collective toes' into the VR 'pond', in the form of a pilot research project. The question that we asked ourselves was "How might VR be used in the geotechnical engineering educational context?" In a first answer to this, we imagined the underground, in a way similar to that which David Macaulay achieved in 2D, as a series of sketches in his attractive and engaging book *Underground* (Macaulay, 1976). An example from this book is shown in Figure 6. Notice at the bottom of the sketch, presumably a father and his child standing on one of the soil layers peering up and admiring the pile foundations associated with several buildings.

As we know, one of the significant challenges of geotechnical engineering is that the underground is opaque and generally hidden. This presents both opportunities, but also challenges. For example, foundations are, almost always, hidden from view (e.g. Fig. 6), as is soil stratigraphy. In this student project, we explored both of these topics – foundations and stratigraphy – from a VR perspective.

Before examining our early exploration in the VR space, a logical first couple of questions are "Why bother with VR?" and "Is VR helpful in education?" In regard to the first question, VR helps one to visualise the non-visible. It is also immersive, in that one feels like they are truly immersed in that environment, and it is also engaging and modern. VR is useful for the promotion of civil and geotechnical engineering, especially to the general public and potential students. It is also helpful for clients to visualise the underground, in a similar fashion to that adopted by architects when visualising yet-to-be constructed buildings.

With respect to the second question, the 'jury is still out.' As the technology is so new, few publications have explored the educational efficacy of VR. Clearly, VR does not replace the 'real thing'. As with most learning technologies, VR should be adopted to augment, not replace, existing pedagogies. As such, it is hard to imagine that VR would be unhelpful.

Back to the final year Honours research project (Coutts et al., 2019). We set ourselves the task of developing a virtual environment involving three multi-storey buildings in the central business district of Adelaide, Australia. Of course, the students shall take all of the credit for what follows, as they are the ones who 'floated to the surface' of this very deep pond, and who, because of their instruction in Civil & Architectural Engineering, possessed reasonably sophisticated 3D modelling skills. The first building selected was Westpac House, which was Adelaide's tallest at the time. The second and third buildings (Ingkarni Wardli and The Braggs Building) were recently constructed at the University of Adelaide's North Terrace campus. The buildings were selected based on the varied nature of their foundations and the availability of construction drawings, which are essential in the development of authentic 3D models. The three buildings are shown in Figure 7.

Westpac House (Fig. 7a) was constructed in 1988, is 132 m tall and is built on a 3.5 m thick concrete raft foundation, whereas the Ingkarni Wardli (Fig. 7b) and Braggs buildings (Fig. 7c) were constructed in 2010 and 2013, respectively, and are both situated on pile foundations. As mentioned above, the construction drawings associated with each building were used to develop the VR simulation. An important element of the project is modelling the stratigraphy of the ground, and borehole logs from each building site were used in the development of the VR simulation.

The buildings and the ground profile were modelled in 3D using the Revit (Autodesk, 2020) software package. In order to create the VR simulation, files were exported from Revit and then input into the Unreal Engine (Epic Games, 2020) gaming software. Examples of the 3D modelled buildings and their associated foundations, from Revit and Unreal Engine, are shown in Figures 8 to 10. The final step of the process was to port the Unreal Engine output file to the Quest headset.

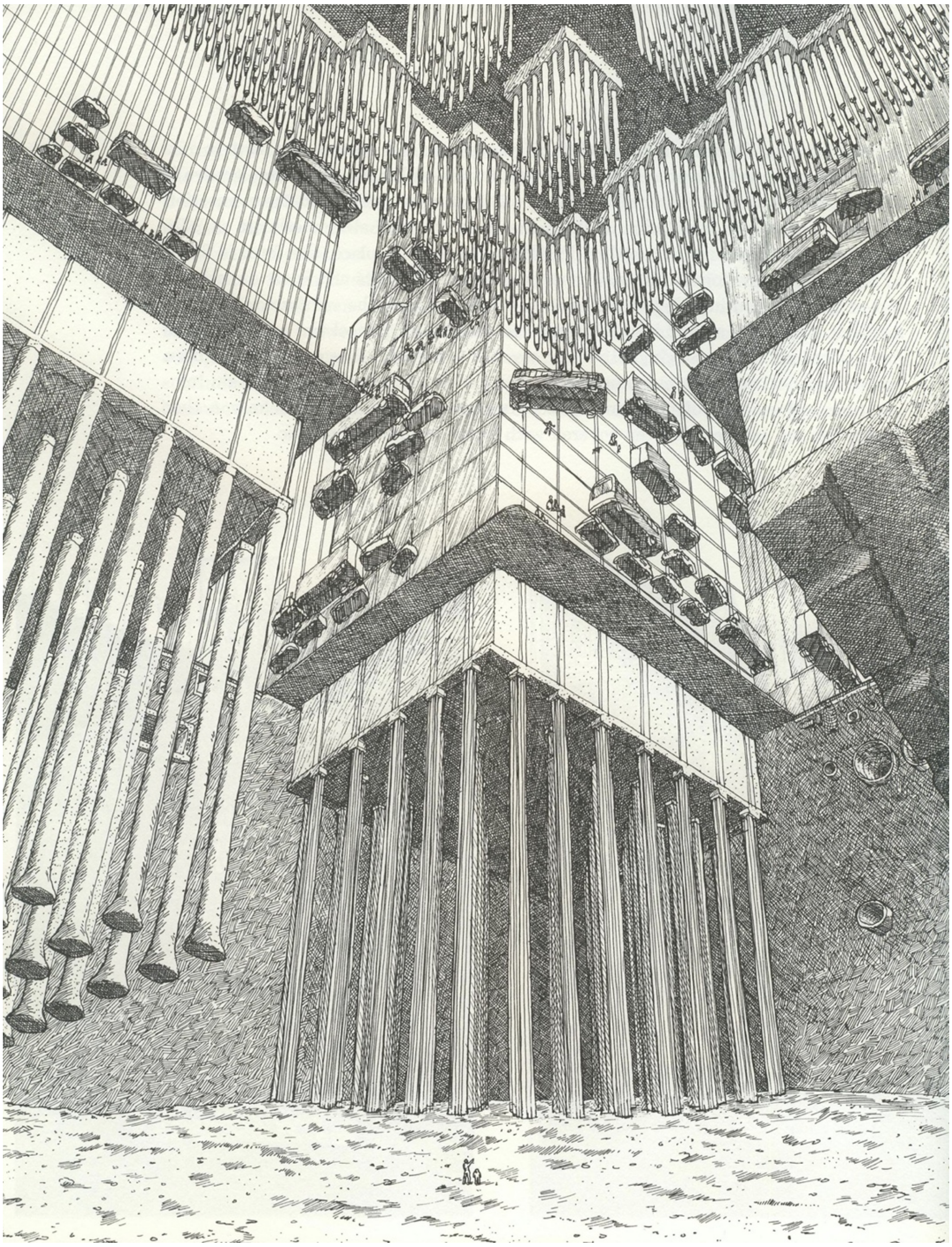

Figure 6. Example of the underground from Macaulay (1976), used by permission

Figure 7. Three multi-storey buildings selected for modelling (a) Westpac House, (b) Ingkarni Wardli, (c) The Braggs Building

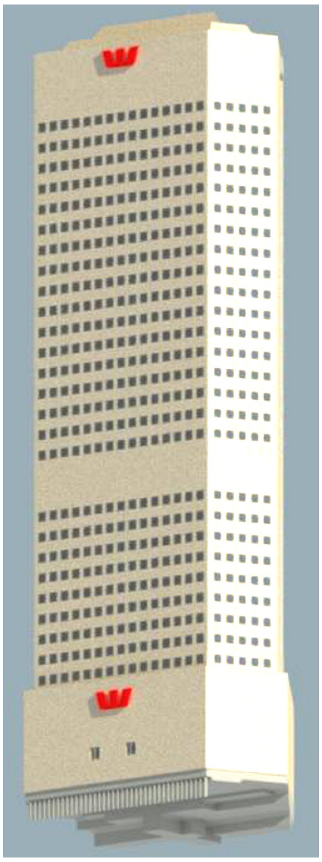

Figure 8. Rendered image of Westpac House from Revit (Coutts et al., 2019)

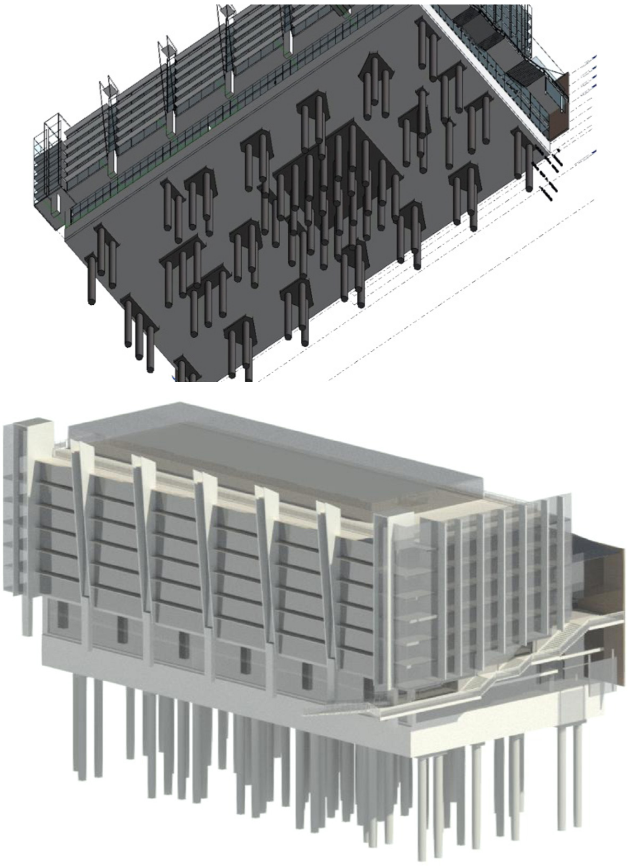

Figure 9. View of the Ingkarni Wardli from Revit: (a) underside, (b) rendered building (Coutts et al., 2019)

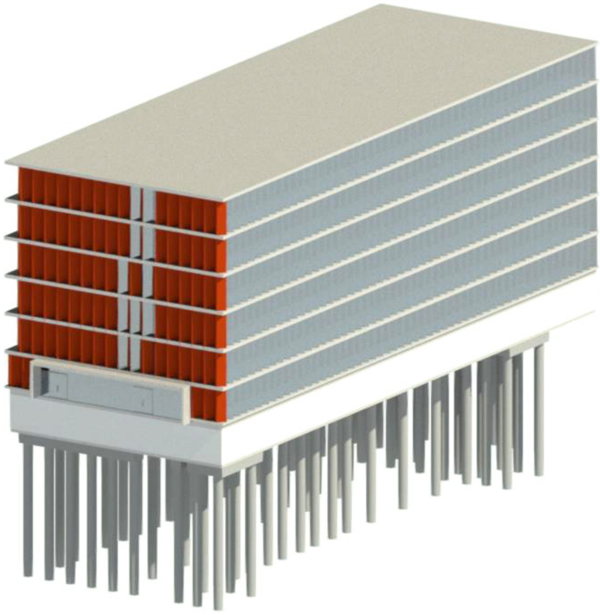

Figure 10. Rendered image of the Braggs building from Revit (Coutts et al., 2019)

The final VR precinct is shown in Figure 11. As Westpac House is located almost 1 km from the two University of Adelaide buildings, a virtual environment was established, where the three buildings are co-located on a single, condensed site, as shown in Figure 11. Even so, as the VR simulation incorporates the buildings at their authentic scale, it is impractical to walk between the buildings within the virtual environment. Hence, a virtual 'teleport' function, which is an element in Unreal Engine, was incorporated into the simulation. Moving the Quest's hand controller joystick up and down, enables the user to move up and down in, effectively, a virtual transparent elevator. This enables the user to be lowered beneath the ground surface. Apart from some modest tinting, in order to highlight the different soil layers, the ground is also transparent, enabling the user to see, and move about, the buildings' foundations.

As one might expect, a 2D paper such as this, is unable to represent appropriately an authentic visualisation of the VR simulation of the three buildings, along with their constructed foundations and associated ground profiles. Nevertheless, in order to provide a sample of what has been achieved within the VR simulation, some images from it are presented in Figures 12 to 16. As can be seen, specific text is also incorporated in the simulation to provide relevant information for the viewer. In future adaptations, this is planned to be replaced by narration.

With this initial exploration into VR, we've only 'scratched the surface' of what might be achieved using this technology. It is expected that the VR simulation will be extended and improved in the future. It has yet to be deployed in a classroom to augment traditional forms of instruction. It has, however, been presented at an exposition of student research work, which was open to the general public, as well as school children. Needless to say, given the cutting-edge nature of the VR technology, as well as the quality of the simulation, it was extremely popular with both school children and the general public.

I'll conclude this brief exposé of VR by imagining where this might lead geotechnical engineering in the future. Just as VR has been incredibly helpful in architecture for visualising yet-to-be-constructed building designs, particularly for clients and the general public, one can imagine that VR would be equally helpful in most sub-disciplines of civil engineering. Various foundation options, and other geotechnical elements, could be visualised prior to construction. Some companies, for example, are using VR to visualise and model cities, such as the Virtual Singapore project (Dassault Systèmes, 2020a), which enhances and unifies city planning and also facilitates the modelling of various scenarios, such as earthquakes and terrorist activities, from which optimal solutions can be derived. Complex civil construction sequences are also being modelled (Dassault Systèmes, 2020b).

VR is also being used as an effective training medium, where, for example, mining engineers can be trained in several aspects including underground mining methods, hazard awareness, working at

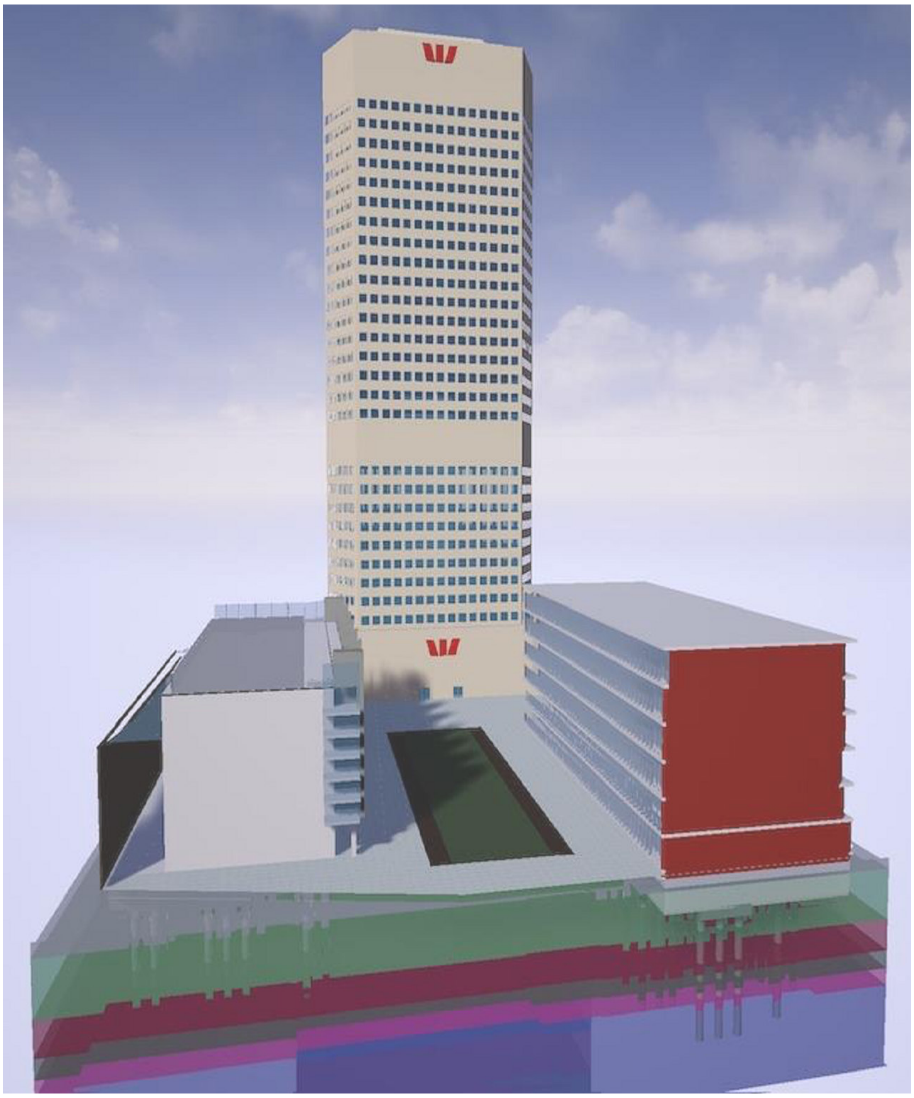

Figure 11. Three multi-storey buildings modelled (Coutts et al., 2019)
(Left to right: Ingkarni Wardli, Westpac House, Braggs Building.)

Figure 12. VR simulation: Precinct (Coutts et al., 2019)
(Left to right: Ingkarni Wardli, Westpac House, Braggs Building.)

Figure 13. VR simulation: View of Westpac House looking up from ground level (Coutts et al., 2019)

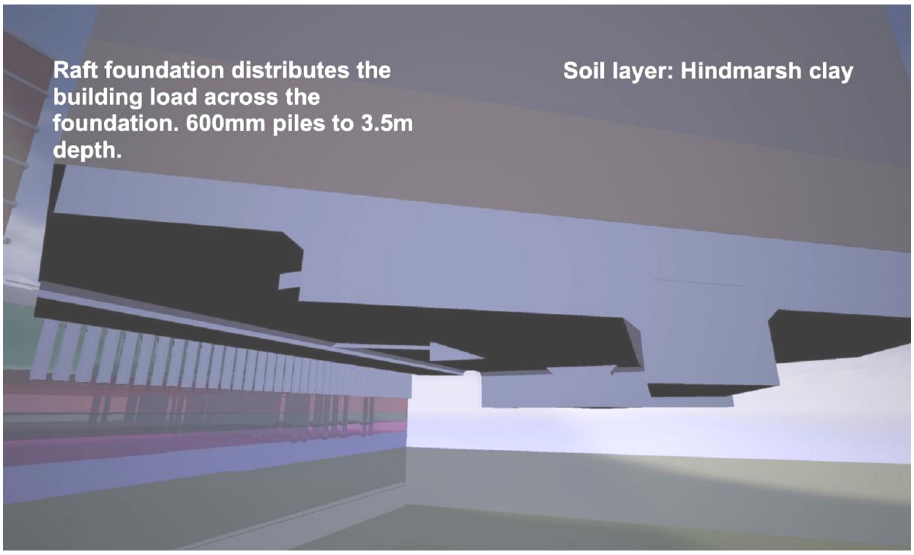

Figure 14. VR simulation: View of Westpac House raft foundation (Coutts et al., 2019)

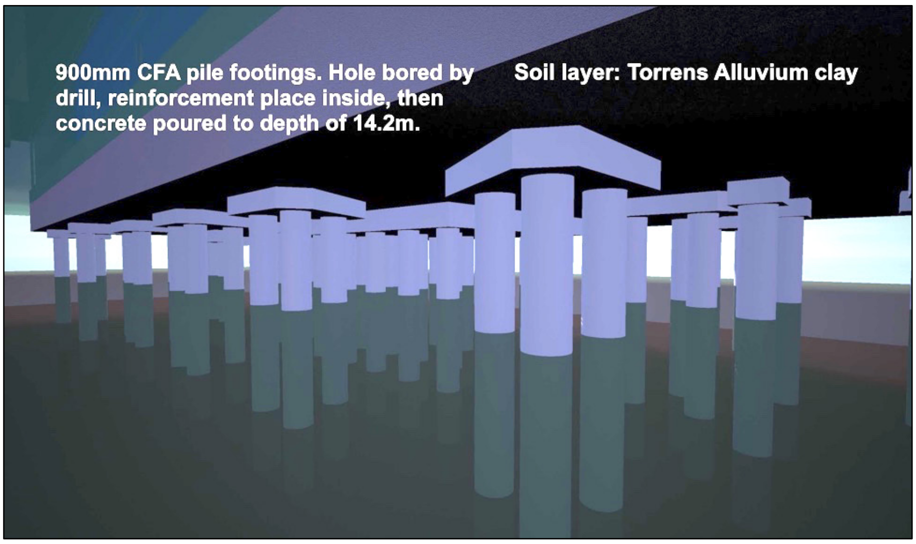

Figure 15. VR simulation: Ingkarni Wardli foundations (Coutts et al., 2019)

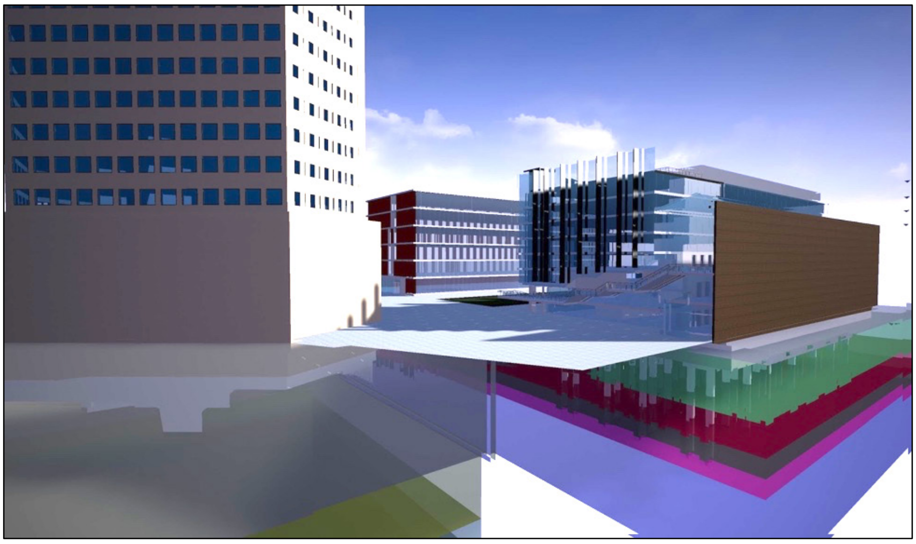

Figure 16. VR simulation: Distant view of precinct (Coutts et al., 2019)

heights, vehicle inspection and data visualisation (Hebblewhite et al., 2013; Mitra & Saydam, 2014). In this way, using an authentic and safe virtual environment, risk of injury during training is effectively eliminated. Similarly, VR is used extensively in construction engineering education and training (Wang et al., 2018). One can also envisage similar training opportunities in the geotechnical engineering context.

VR can also assist with visualising complex stratigraphies and ground profiles in order to better understand the ground, and also facilitate the design of optimal geotechnical structures. In a similar way, complex underground services can be visualised using VR so that, again, geotechnical structures can be designed effectively and efficiently.

A very useful opportunity, but one that is likely sometime in the future, is linking numerical modelling with VR. One can imagine modelling a structure using established geotechnical engineering computer analysis (such as the finite element, finite difference or discrete element methods), modifying a range of geotechnical parameters (such as shear strength, compressibility or stress paths), and modelling the subsequent system performance. By linking these dynamically with the VR system, one could visualise the numerically modelled results. Whilst this would be incredibly valuable in practice, it would also be so in geotechnical engineering education, where students could explore various cause-and-effect scenarios in order to improve their understanding.

5 Conclusions

This paper has examined three aspects of geotechnical engineering education. Firstly, it has been advocated that the principles of critical state soil mechanics (CSSM) be universally adopted in the education, at undergraduate level, of civil engineers. Not the details of the Cam Clay model, or similar, but the linking of load, strength and volume change, which is one of the great strengths of CSSM. It has been argued that CSSM also effectively models real soils, such as those that are unsaturated and those that undergo liquefaction. Secondly, the flipped classroom pedagogy has been briefly examined and it has been argued that it adds value in contemporary geotechnical engineering education. Finally, the immersive technologies of 360-degree cameras and virtual reality have been presented in order to explore whether they might augment learning and teaching in geotechnical engineering. It is concluded that they are likely to be helpful.

Acknowledgements

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Invited author's bio

Mark Jaksa, University of Adelaide, Australia

Mark Jaksa is Professor of Geotechnical Engineering in the School of Civil, Environmental and Mining Engineering at the University of Adelaide, Australia. He has been an academic for more than 30 years, before which, he spent 4 years practising as a consulting geotechnical and civil engineer in Adelaide and Canberra in Australia. He has a Bachelor of Engineering (Honours) degree in Civil Engineering and a PhD, both from the University of Adelaide. He has published more than 175 papers, chapters and reports on various aspects of geotechnical engineering research and teaching. His primary areas of expertise are in the characterisation of the spatial variability of soils, probabilistic analyses, artificial intelligence, ground improvement, unsaturated soils and enhancing learning in geotechnical engineering. He has received several awards recognising his contributions to learning and teaching in geotechnical engineering. Mark is a former Chair of the Australian Geomechanics Society and immediate past Vice-President for Australasia and Treasurer of the International Society for Soil Mechanics and Geotechnical Engineering. He is also a past Chair of the ISSMGE's Technical Committee, TC306, on Geo-engineering Education and a member of TC304, on Risk Assessment and Management.

Invited Papers

Common Instructional Practices Grounded in Evidence

S.A. Ambrose

Northeastern University, Boston, United States
s.ambrose@northeastern.edu

ABSTRACT: Effective teaching is a complex process because it requires that faculty understand how learning actually works: how does information become knowledge and skills that students "own" and can use fluently and flexibly in other contexts beyond our particular course, and what strategies facilitate this deep and long-lasting learning? This paper provides examples of strategies that are based in research on learning, with the premise that we can design courses and pedagogy to enhance learning by creating the conditions that prompt students to engage in the behaviors we know lead to learning.

Keywords: evidence-based, instructional strategies

1 Introduction

Many faculty members, through experience, have identified and used successful pedagogical strategies that have resulted in deep student learning, and yet they cannot always articulate why those strategies have been successful. Some faculty have also recognized that certain strategies work with some cohorts of students and not others, and again they do not necessarily know why. This paper, based on *How Learning Works: 7 Research-Based Principles for Smart Teaching* (Ambrose et al., 2010), focuses on a set of common instructional practices and provides the underlying evidence for why these practices are effective.

2 Diagnostic Learning Assessments: The Importance of Prior Knowledge

Professor X begins his course by asking students the following question: by show of hands, how many of you know what permeability is? Porosity? Compressibility? Shear strength? To his delight, the vast majority of students raise their hands, and off they go into the new semester. Professor Y begins her course with a few problems that will allow students to demonstrate their understanding of permeability, porosity, compressibility, and shear strength. These problems are not graded and are administered solely for the purpose of helping the professor gain a sense of the knowledge her students possess.

Which of these approaches will provide accurate information about students' prior knowledge and, most likely, lead to a better result, e.g., better student performance, less faculty frustration? If you chose the second scenario, you are correct. What we know from research is that novices (someone without a lot of experience in the area) often overestimate what they know and often define "knowing" very differently from the faculty. For example, students in the first scenario might define "know" as "I've heard of it" or "I remember seeing it in the text in the last course" or "I could define it", while we, as educators, define "know" as the ability to define a term or concept, and also know both *how* to use it and, most importantly, *when* to use it. In other words, *knowing what* is very different from *knowing how* which is very different from *knowing when*. It's not that the students in the first scenario are deceitful, it's often that they don't know what they don't know. The second scenario takes the students' own view of their knowledge and skills out of the equation by simply requiring that they demonstrate what they know.

Why is this important? Because prior knowledge is the lens through which we take in all new information as we build our understanding and knowledge base. This lens influences how students filter and interpret incoming information, and if and how they connect it to existing knowledge. If information in that knowledge base is inaccurate, incomplete, insufficient or inactive, then the foundation is shaky, making it difficult for students to integrate new knowledge, thus impeding their learning (Ambrose et al., 2010). Students learn more readily and deeply when they can connect what they are learning to what they already know. As a result, knowing what students actually know, or think they know, is vital to their success in our courses, allowing us to build from reality instead of our hopes or expectations (which may often be inaccurate).

In order for prior knowledge assessments – like the one in the second scenario – to be effective and successful, we have to be flexible and adaptable enough to fill the gaps identified, correct misconceptions, show students conditions of applicability (i.e., when to use the facts, concepts, models, etc. they have acquired), etc., which may mean deviations from the course plan we prepared. The good news, however, is that the assessment can also confirm what students actually do know and enable us to leverage and build on that knowledge and those skills.

3 Graphic Syllabi and Concept Maps: The Value of Organizational Structures

The first page of Professor A's syllabus is a graphic depiction of the course, while Professor B presents students with a concept map she developed to represent her view of the content. Why are these effective learning strategies? In both cases, these strategies provide a visual representation of organization: the graphic syllabus shows the organizational structure of the course, while the concept map shows the organizational structure of the content.

A graphic syllabus enables students to clearly see the overarching structure of the course and to continually situate what they are learning within that overall structure, as well as where they are headed. Why is that important? As experts in our field, we walk around with "pictures" (some call them schemas, knowledge structures, organizational structures) which we have unconsciously created: these organizational structures represent complex networks of facts, concepts, principles, procedures, etc. that are organized around meaningful features. These rich and meaningful knowledge structures allow us to access what we need when we need it; in fact, part of what makes us experts in our field is that we not only have a vast amount of knowledge, but that we have organized it in a way that makes it easy to retrieve and use (Ambrose et al., 2010). Depending on the level of students you are teaching, they may have sparse and superficial knowledge structures (think first year undergraduates) or partially accurate but incomplete knowledge structures (think third year undergraduates), neither of which will serve them well in the future. A graphic syllabus can provide students with the big picture view that presents key concepts or topics in the course and highlights their interrelationships.

A concept map illustrates the central principles and key features around which you, as an expert, organize your knowledge (Novak & Canas, 2008). They are typically "drawn as nodes and links in a network structure in which nodes represent concepts, usually enclosed in circles or boxes, and links represent relationships, usually indicated by lines drawn between two associate nodes. Words on the line, referred to as linking words or linking phrases, specify the relationship between the two concepts (Ambrose et al., p. 228)."

Both graphic syllabi and concept maps model for students the importance of intentionally organizing information to guide further learning, retrieval and use across situations. It really is true: a picture is worth a thousand words!

4 Authentic, Real World Assignments: Value as a Key to Motivation

Professor G goes out of his way to tap industry colleagues for examples of authentic, real world challenges and problems, as well as using his current consulting experience, to provide examples and design assignments for students in his courses. Why is this important?

Motivation is the personal investment an individual has in reaching a desired state or outcome (Maehr & Meyer, 1997), and in academe it influences the direction, intensity, persistence and quality of the learning behaviors in which students engage. In our courses, we hope that the desired state or outcome is the learning, although too often it's the grade! In either case, the question is why students would invest time and energy in our course given all the other things going on in their lives, e.g., other courses, co-curricular activities, work, family demands, romances. One key element of the answer is value; students will be more motivated to pursue a goal that has high value to them (Ambrose et al., 2010). Lucky for us, there are three sources of value: the first is attainment value, which represents the satisfaction that one gets from accomplishing a goal; the second is intrinsic value, the satisfaction one gets from simply doing the task; and the third is instrumental value (also called extrinsic rewards), which represents the degree to which an activity or goal helps one to accomplish other important goals, like securing a high status job, recognition, a good salary (all longer-term goals). The example of authentic, real world problems falls into the final category, as this strategy enables students to see the relevance to future work in the tasks they are assigned, and provides a context for understanding concepts and theories and their applicability in the real world. In other words, these examples reinforce *knowing when* to apply their knowledge (which is different from *knowing what* and *knowing how*, as discussed in the section on diagnostic learning assessments). Without these connections to reality, course content often seems abstract to students, and given competing demands for their time and attention, they may focus on other courses where they clearly see value in accomplishing their short-term or longer-term goals.

5 Identifying the Strategy, Not Solving the Problem: The Rationale behind Isolated Practice in Gaining Mastery

Midway through her course, Professor M gives students a homework assignment, and then a quiz, in which she asks them to identify the statistical test they would use (e.g., one sample t-test, binomial test, chi-square goodness of fit, one-way ANOVA, paired t-test) to solve a set of problems, *without actually solving the problems*. Why does she do this, it's solving the problem that is most important, isn't it?

As experts in our field, tasks that seem easy to us can hide complex combinations of component knowledge and skills. Think about the many steps (e.g., turn ignition, adjust mirrors, put car in reverse, apply brakes), facts (e.g., traffic laws, street signs) and skills (e.g., parallel parking, performing a three-point turn) you engage on a daily basis when you drive your car. Actually, chances are you NEVER think about those things because they have become effortless and second nature to you given how long you probably have been driving. But all of those component parts are often overwhelming to someone just learning to drive. In order to become a safe driver, you need to practice many of these steps and skills in both isolation (e.g., balancing the gas and brake pedals in a standard transmission car) and in an integrated way (using your mirror and turn signal when switching lanes). The same is true in problem solving: in order to be effective, you need to first identify the nature of the problem, understand the end state needed, decide on a strategy to get there, execute the strategy, adapt execution based on continual monitoring or difficulties encountered, and evaluate the outcome. In solving a statistics problem, one of the most important decisions a student will make is identifying the appropriate test to use in analyzing the data. If they get this wrong, there is no recovery. In order to both help students understand the importance of choosing the most appropriate statistical test, and to give them practice doing so, Professor M focuses them on this one component part of solving problems.

Mastery requires that students first gain the component knowledge and skills they need, practice integrating them, and know when to apply what they have learned (Ambrose et al., 2010). In order for us to teach effectively, we need to be able to deconstruct or unpack complex tasks (that we often don't "see" as complex) so that we can clearly model for students the steps involved and the knowledge and skills needed to complete the task.

6 Polling in the Classroom: The Significance of Timely and Constructive Feedback

Professor S uses interactive technology in his classroom: he poses a question to students and asks them to respond; if a large enough proportion of students answer incorrectly, he then asks them to discuss the question in small groups, and then polls them again. This seems to take a lot of precious classroom time, is it worth it?

Absolutely! This strategy facilitates a number of key elements in the learning process. First, it enables the instructor to gather real-time feedback on students' understanding and intercede in the learning process as learning is happening, as opposed to giving feedback on a misconception in a problem set, three days after a student has handed it in (Ambrose et al., 2010). For example, if, after the second polling, a significant number of students still respond incorrectly, the professor can provide further explanation of the concept and alternative examples. In other words, timing and the nature of feedback is most effective when students can make the most use of it; for example, addressing misconceptions, identifying missteps, determining lack of conceptual understanding versus mathematical errors, etc., promotes learning best, when the learning is occurring. This is true because the timely and constructive feedback helps students to stay on track and addresses their errors before they become entrenched.

Second, this strategy facilitates student discussion of content and peer-to-peer learning, as students explain their respective rationales for their response and “teach” each other. This does not happen if students are working alone on problem sets in the library or their dorm room. This strategy also bolsters other useful skills such as working in groups and communicating effectively.

7 Multiple and Diverse Examples: Contributing to a Positive Course Climate

Professor T spends a lot of time searching for examples, problem sets and projects that will “speak” to all of her students, as opposed to simply using the examples from the book and problem sets provided by the publisher. How does this extra effort pay off?

Examples help students to better understand theories, concepts, etc., and problems sets and projects provide students with the opportunity to apply what they have learned; all three help students learn how concepts and skills operate in a variety of contexts and conditions. However, if the nature of the examples, problems and projects are alienating to students – e.g., they don’t feel connected to the content, they don’t feel they belong in the course/field – then learning can be impeded. Given the diversity within college classrooms in 2020 (e.g., gender, cultural, socio-economic, age), an example that works to solidify a concept for one group may not do the same for another. For example, referencing the 2008 recession in the U.S. does not serve to elucidate concepts for either younger students who were children at the time or for those from countries not affected by it. Or using a cultural example from a famous “failure” in construction (e.g., Leaning Tower of Pisa, Tacoma Narrows Bridge, Lotus Riverside Complex) may illustrate a misconception to students from that region but not illuminate it for others from around the world. In all of these cases, multiple and diverse examples that connect with various members of the student population validate that they all belong.

Why is this sense of belonging important to learning? Because students are not only intellectual beings, but also social-emotional beings, and they bring their whole self into the classroom. As a result, these dimensions interact within the classroom climate to impact learning (Ambrose et al., 2010). While human beings continue to develop throughout their lives, it is important to remember that emotional and social processes are particularly salient during the college students’ phase of life (circa 18 – 24). This is the time that young people are beginning to think about their professional identity; question their purpose, values, beliefs; exert independence and autonomy; establish new social networks; negotiate differences, etc., all of which intersect their intellectual, social and emotional selves (Chickering, 1969). Something as seemingly innocuous as using textbook examples that are gendered and culturally biased can create an environment where certain students feel unwelcome, or where they feel the pressure of “representing” their gender or ethnic identity. Intellectual pursuits interface with socio-emotional issues, and the emotions these examples may invoke can overwhelm the cognitive capacity to engage with the content, hence hindering learning. In other words, we need to remember that we teach students (who, like us, are complex human beings), not just content, and that we can create a climate in our course to enable or hinder learning for all of our students.

8 Reflection: A Requirement for Becoming a Self-Directed Learner

Professor Q requires every student, for every major assignment, to write a paragraph or two on what they found to be difficult about the assignment, what they would do differently (e.g., would they make different assumptions or take a different approach), what knowledge they need a better grasp on, and what skills they need to work on. What purpose does this serve?

The world in which we live today, and our graduates’ future professional success, requires that they have the ability to continue to learn throughout their lives. Some will have multiple jobs and even careers, and others will find themselves continually upskilling, as their work roles and responsibilities change because of automation and globalization. Becoming a self-directed learner with strong metacognitive skills [defined as the process of reflecting on and directing one's own thinking (National Research Council, 2001, p. 78)] entails graduates being able to assess new tasks (including the goals and constraints), evaluate their own strengths and weaknesses (per knowledge and skills), plan their approach to completing the task, apply the strategies identified and monitor their own performance, adjust approach and/or strategies if necessary, and finally reflect on the experience (Ambrose et al., 2010). It is the final component of this process that Professor Q is asking students to engage in.

As professionals and experts in our respective fields, we engage in this process continually, often without consciously recognizing that we do so. To illustrate the reflection stage of the metacognitive process, think about how many times you have hit the button to submit a proposal, journal article or book manuscript, and then immediately thought about a different way you could have structured the document, or a research study you should have cited, or a statistical test you could have done to strengthen the data analysis section. We do this all the time! Now think about your students: do you believe they engage in that same reflective process once they submit a project or problem set? Typically, they are looking forward and thinking about all of the other assignments they have to submit, not ruminating on what they could have done differently. And yet that is a vital part of the learning process, particularly one that can impact future learning and performance.

Because this doesn't come naturally to students, we can build this (the entire metacognitive process, not just the reflection piece) into our assignments and facilitate their ability to become self-directed, lifelong learners.

9 Conclusion

The above examples illustrate the learning principles from *How Learning Works: Seven Research-Based Principles for Smart Teaching*. While there are many more strategies that connect with the principles, the point of this paper is that we, as educators, should understand the underlying reasons that strategies we use work to enhance student learning. In other words, there is power in understanding how learning actually happens, so that we can design educational experiences (e.g., courses, in-class exercises, labs, projects) to fully engage students in the learning process. Cognitive psychologist and Nobel Laureate Herbert A. Simon (and a mentor to this author) was often heard saying that "Learning results from what the student does and thinks and only from what the student does and thinks. The teacher can advance learning only by influencing what the student does to learn." This quote sums it up succinctly: we can better facilitate deep and long-lasting learning if we utilize what we know about learning in our design and teaching processes.

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Invited author’s bio

Susan Ambrose, Northeastern University, USA

Dr. Susan Ambrose, Professor of Education and History, is Senior Vice Chancellor for Educational Innovation at Northeastern University. She is an internationally recognized expert in college-level teaching and learning, and has worked with university faculty and administrators throughout the United States and around the world. Her work focuses on translating research to practice in the design of curricula, courses and educational experiences for both undergraduate and graduate students. Prior to Northeastern University, she served for 25 years at Carnegie Mellon University, as Associate Provost for Education, Director of the Eberly Center for Teaching Excellence, and a Teaching Professor in the Department of History. Dr. Ambrose is co-author of five books. The most recent is titled Higher Education’s Road to Relevance: Navigating Complexity (Wiley/Jossey-Bass, 2020). Her last book, How Learning Works: Seven Research-based Principles for Smart Teaching (Jossey-Bass, 2010), has been widely praised for integrating fundamental research in the learning sciences and practical application. The book has been translated into Japanese, Korean, Chinese, Spanish, Italian and Arabic. She has also published numerous articles in such journals as The Journal of Higher Education, The Review of Higher Education, Research in Higher Education, Quality Approaches in Higher Education, and the Journal of Engineering Education.

When Graphs are More than 'Pictures': Visual Literacy as a Challenge for STEM education

V. Christidou

Aristotle University of Thessaloniki, Thessaloniki, Greece
vchristidou@nured.auth.gr

ABSTRACT: Science Technology Engineering and Mathematics (STEM) education relies heavily on visual images. Images constitute a system of meaning making, parallel with language or symbolic representations. Understanding, creating and communicating with visual images in STEM requires competence in using the specialized visual codes pertinent to the STEM disciplines. Therefore, STEM Visual Literacy (STEM-VL) is considered as a fundamental aspect of STEM literacy, hence a crucial instructional objective for all education levels. The development of students' STEM-VL presupposes that they are continually, systematically, and purposefully engaged in active 'reading' and construction of visual representations during instruction. The paper reviews recent research in the field of STEM-VL and proposes a taxonomy of commonly used categories of STEM visual images. Research-based instructional practices to 'scaffold' the development of students' STEM-VL are discussed. Lastly, implications for teaching and research aimed at promoting students' STEM-VL are outlined.

Keywords: Images, Multimodality, Scientific Visual Literacy, STEM Education, Visual representations

1 Multimodality, multiliteracies and visual literacy

We live in a multimodal, image-saturated environment. In this environment, effective communication entails being able to comprehend and use different representational modes, such as language, image, sound, movement, etc. and their co-deployment. Thus, the notion of 'literacy', in the traditional sense of being able to read and write, has been replaced by 'multiliteracies', which call for preparing students to master a range of representational modes. In this multimodal communicative landscape, the visual mode, i.e. the use of images, is pervasive. Images of all kinds are used to effectively convey information and to support the construction of meaning (Cope & Kalantzis, 2009; Danos & Norman, 2009; Jarman et al., 2012; Jewitt, 2008; Lemke, 1998a, 1998b).

The dominance of images underscores the importance of preparing students as active readers, learners and producers of multimodal texts. The possibilities of combining image and verbal text are practically infinite. Thus, students need to be competent in selecting and evaluating information, in modifying and reinventing meaning in creative ways. Therefore, we should consider how images can be 'harnessed', to the benefit of education (Avgerinou & Pettersson, 2011; Jarman et al., 2012; Jewitt, 2008; Matusiak et al., 2019).

This discussion brings forward *visual literacy* as a major challenge for education worldwide (Jewitt, 2008). Several attempts to define visual literacy have been made since the '60s. Despite particular differences, relevant theories converge on some key assumptions regarding visual literacy (Avgerinou & Pettersson, 2011; Kedra, 2018; Trumbo, 1999):

- There is a visual language, parallel to verbal, with its distinct grammar, syntax and vocabulary;
- Visual literacy involves the abilities to (a) comprehend and interpret, (b) create and (c) think and learn by means of visual images;
- The competences related to visual literacy can be taught, developed and improved.

The delay of educational systems to set visual literacy as a priority (Trumbo, 1999) possibly originates from the illusion that its associated competences are intuitively acquired. However, visual language is complex (Avgerinou & Pettersson, 2011). The higher-order competences related to visual literacy are cognitively demanding and require deliberate instruction (Ainsworth, 2008; Matusiak et al., 2019; Rau, 2017).

2 Images in STEM education

Science, Technology, Engineering and Mathematics (STEM) involve intensely multimodal discourses. They rely on verbal, symbolic/mathematical and visual resources, interweaved in sophisticated explanations (Anagnostopoulou et al., 2012; Lemke, 1998b; Ramadas, 2009; Rau, 2017; Trumbo, 1999). The fundamental STEM concepts are themselves multimodal in nature. No verbal text can convey an identical meaning to that of an image; no graph can carry the exact same meaning with a mathematical equation (Lemke, 1998a; Cope & Kalantzis, 2009). For instance, a physics, or an electrical engineering expert conceptualize electromagnetic waves by means of (at least) three different semiotic modes: the verbal (Figure 1, left), the symbolic/mathematical (Figure 1, right) and the visual (Figure 2).

Maxwell's equations

1. The electric flux through a closed surface is proportional to the charge enclosed.
2. There are no magnetic monopoles; the total magnetic flux through a closed surface is zero.
3. Change of magnetic flux produces an electric field.
4. Electric currents and changes in electric flux produce a magnetic field.

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

Figure 1. Maxwell's equations on electromagnetic waves expressed verbally (left) ["Maxwell's equations" by MITOPENCOURSEWARE (CC BY-NC-SA), and symbolically (right) ["Differential form of Maxwell's equations by Oliver Heaviside", by Yassine Mrabet (2008) (CC BY-SA 3.0)]

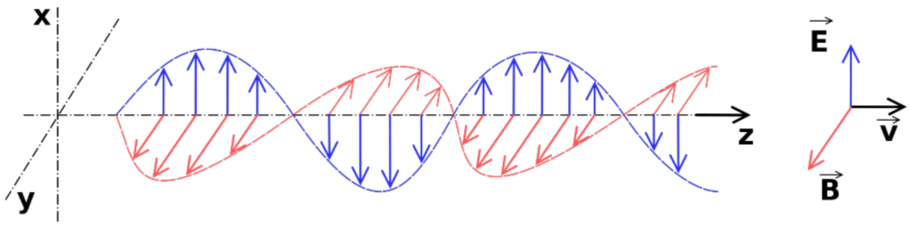

Figure 2. Visual representation of an electromagnetic wave ["Onde electromagnetique", by Emmanuel Boutet (2007) (CC BY-SA 3.0)]

Visual images are an intrinsic part of thinking and practice in any STEM-related field. They are used to represent phenomena and entities and describe data in concise and coherent ways. Visual images are then an essential aspect of STEM literacy (Ainsworth et al., 2011; Anagnostopoulou et al., 2012; Glazer, 2011; Rau, 2017; Roth & Bowen, 2003).

Similarly to STEM concepts, STEM education is also multimodal. Visual representations pervade classroom instruction, textbooks and digital teaching material. During STEM classes, teachers and students communicate using verbal, motor and visual resources. Images are increasingly used to introduce, define and analyze new concepts. They are extremely valuable in rendering abstract concepts visible and concrete, thus supporting the development of scientific competences along with conceptual understanding of the entities they represent. Besides, images and verbal language highlight different aspects of reality: images emphasize spatiality and synchronicity, while verbal language emphasizes temporality and sequentiality (Bowen, 2017; Carifio & Perla, 2009; Cope & Kalantzis, 2009; Jarman et al., 2012; Jewitt, 2008; Lemke, 1998a; Rau, 2017; Trumbo, 1999).

Likewise, learning in STEM is also multimodal. It involves constructing mental models that integrate information mediated by artefacts, verbal expressions, symbolic representations (e.g. mathematical or chemical formulae), visual images (e.g. diagrams, maps) and gestures. Visual images are key representational resources for students to develop their understanding of STEM concepts. Multimodal learning in STEM also assumes that the learner is competent in 'translating' between different representations of the same entity. Multiple representations are common practice in the STEM fields because they provide complementary information and allow deeper understanding, if embedded in cohesive mental models (see Figures 1 and 2). More specifically, multiple *visual* representations enhance understanding of abstract concepts (Figure 3). One image can support students in interpreting other, more complex and demanding images (Ainsworth, 2008; Britsch, 2013; Cheng et al., 2001; Cook et al., 2008; Matusiak et al., 2019; McTigue & Flowers, 2011; Rau, 2017).

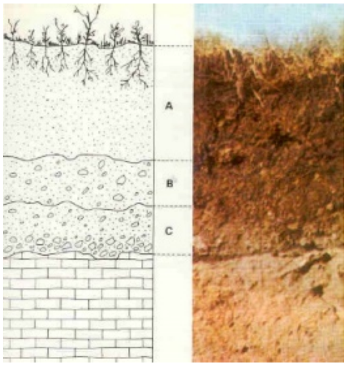

Figure 3. Multiple (dual) representation of the structure of a typical soil
["Estructura vertical de un suelo tipico. Suelo rojo mediterráneo" by Carlosblh (2006) (CC BY-SA 3.0)]

Despite widespread use of visual images, education has not been effective in meeting the communicative requirements for students and future scientists and engineers posed by multimodality and intense visuality. STEM teaching often emphasizes verbal and mathematical language, overlooking visual communication, especially in higher education (Kędra, 2018; Ramadas, 2009). Most often in secondary education images in a text are seen as decorative, thus not significant for learning. Accordingly, teachers do not pay much attention to students' understanding, production and use of visual images, while assessment (i.e. tests, examinations) is mostly logocentric (Bowen, 2017; Britsch, 2013; Cope & Kalantzis, 2009; Jewitt, 2008; Lemke, 1998b; Matusiak et al., 2019). This "verbal bias" (Coleman & Dantzler, 2016, p. 36) significantly restricts students' familiarization with visual representations and their ability to use them adequately. Additionally, students themselves often view textbook illustrations primarily as ornamental, paying minimal attention to the information they convey (Matusiak et al., 2019; McTigue & Flowers, 2011). However, images in STEM fields are -exactly like specialized verbal terminology- important meaning-making devices and deriving the relations between depicted variables requires significant effort from students (Åberg-Bengtsson, 2006).

3 STEM visual literacy

3.1 Defining visual literacy in STEM education

The previous discussion points to the necessity of explicitly teaching students how to interpret and use images in the context of STEM. This would enable them to develop reasoning skills and become more effective in communication and problem solving within STEM subjects (Jewitt, 2008; McTigue & Flowers, 2011; Moline, 2011; Rau, 2017; Trumbo, 1999). These competences are at the intersection of visual literacy and STEM literacy and describe *STEM visual literacy* (STEM-VL), which involves (Byrd, 2018; Danos & Norman, 2009):

- A complex form of communication using visual language to express spatial and/or temporal relations that could not be conveyed by verbal or mathematical signs alone;
- The ability to understand, interpret and create images with specialized STEM-related content.

Therefore, mastering the 'STEM visual language' in order to understand and create expert-like images, presupposes the acquisition of high-level visual abstraction, which requires specifically focused instruction (Coleman & Dantzler, 2016; Kędra, 2018; McTigue & Flowers, 2011).

3.2 Proposing a taxonomy of STEM visual images

STEM education relies on an enormous range of images requiring STEM-VL competences to be used appropriately and effectively. Several classification schemes of STEM visual images have previously been proposed (Danos & Norman, 2009; Koulaidis et al., 2002; Kress & van Leeuwen, 1996; Moline, 2011). Figure 4 suggests a taxonomy of visual images with which students are expected to become familiar as STEM apprentices (Christidou, 2018). The taxonomy involves three distinct dimensions, namely (a) the *specialization of the visual code*; (b) the *scientific thinking competences* required for their comprehension; and (c) the *types of representations* in which the two aforementioned dimensions apply.

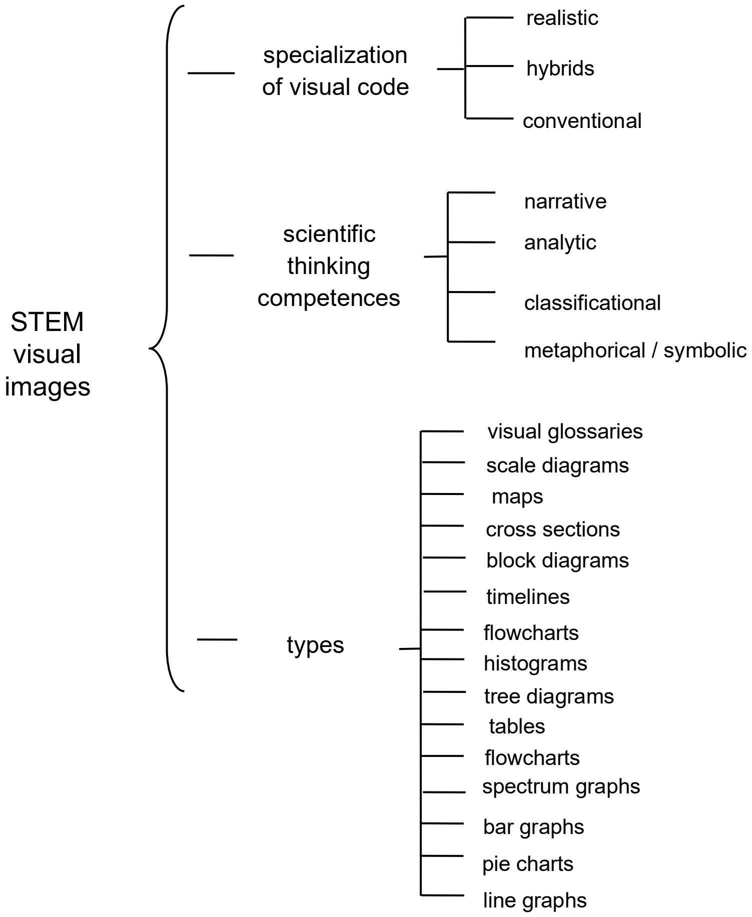

Figure 4. Taxonomy of STEM visual images

In regards to *specialization of the visual code* images can be *realistic*, i.e. depict entities as perceived by the human eye. These images involve photographs or sketches and even non-specialized readers readily understand most of them (e.g. the right-hand photograph in Figure 3). At the other end of the spectrum, *conventional* images are highly specialized images following discipline-specific visual conventions. Typical examples of conventional images are graphs (Figure 5), or depictions of dynamic fields (e.g. electric fields, flow fields). Conventional images are the most challenging to interpret and normally are addressed to expert readers who are both familiar with the conceptual content (e.g. magnetic fields) and the visual conventions used (e.g. field lines). *Hybrids* are visual images that include realistic and conventional elements. Cross-sections (Figure 6), block diagrams (Figure 7) and maps are usually hybrids (Koulaidis et al., 2002).

The second dimension of the taxonomy, i.e. the *scientific thinking competences* required to effectively interpret or construct an image, relates to the function of images in a text. *Narrative* images represent events that evolve in space and time, denoted by lines or vectors indicating direction. Timelines and graphs (Figure 5) are representative examples of narrative images. *Analytic* images represent the parts forming a whole, such as a map indicating a continent and its constituent countries, or a slope cross section (Figure 6). Classificational images present relations between depicted elements, for instance different categories of the same class (Figure 7), or relations of subordination between categories and subcategories. In *metaphorical* images, the *symbolic* denotation of depicted elements dominates (Koulaidis et al., 2002; Kress & Van Leeuwen, 1996).

The two aforementioned dimensions are realized in different *types* of visual images. Thus, the third dimension of the taxonomy involves diagrams, maps, cross sections, tables, histograms, timelines, graphs, etc. (Moline, 2011).

Figures 5, 6 and 7 present three different images belonging to different categories concerning the dimensions of specialization of visual code, scientific thinking competences and image types comprised in the taxonomy. It should be noted that in regards to the second dimension, a STEM visual image can often require different scientific thinking competences at the same time. For example, Figure 6 has both an *analytic* (the soil mass consists of two parts: the failing mass and the stable mass) and a *narrative* function (implies that the slope may fail), while Figure 7 is simultaneously *classificational* (indicates different landslide types), *analytic* (indicates the parts of each landslide) and *narrative* (depicts landslide processes).

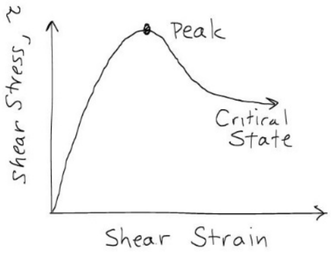

Figure 5. A conventional, narrative line graph ["Typical shear-stress shear-strain curve for a soil showing the peak and critical states", by Bruce Kutter (2010) (CC0 1.0)]

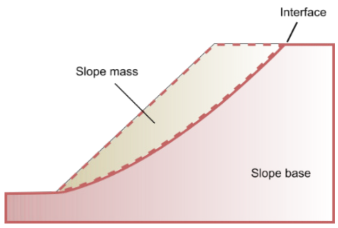

Figure 6. A hybrid, analytic-narrative, cross section (2D) ["Slope 2d plain", by Biswajit Banerjee (2015) (CC BY-SA 3.0)]

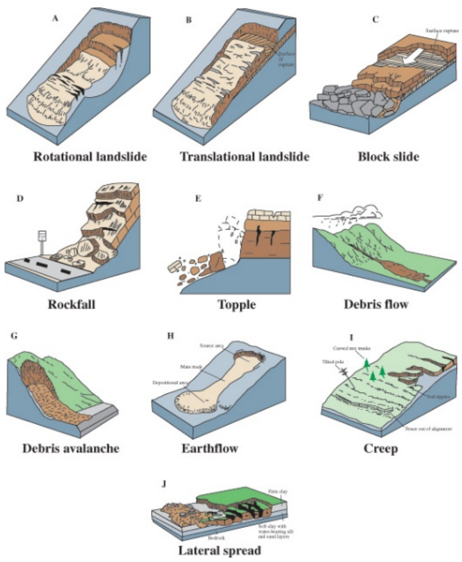

Figure 7. A hybrid, classificational-analytic-narrative set of block diagrams (3D) ["Landslide Types and Processes", by USGS (2004) (CC0 1.0)]

4 STEM Visual literacy: Challenges for students

Interpreting STEM-related images is a complex and demanding process. For instance, understanding a graph involves three levels, namely extracting points, finding trends and relationships, and generalizing the depicted information (Glaser, 2011). It also involves recognizing the visual conventions, symbols, or equations visualized, along with understanding the conceptual content to which it refers. Therefore, in order to interpret the graph in Figure 5 students are expected to be acquainted with Cartesian coordinate systems and with what the lines in a graph indicate about the relationship between the variables. They are also required to comprehend the concepts involved, i.e. shear stress, shear strain, peak and critical state and the relations between them. Lastly, in this specific example, the students are expected to recognize that, in principle, a test producing the results depicted in Figure 5 can be conducted either by controlling stress (stress is the independent variable) and measuring strain, or by controlling strain (strain is the independent variable) and measuring stress (like the experiment shown in Figure 5); however, in both cases strain will be plotted in the x axis, i.e. the independent and dependent variables can swap between the x and y axes in this graph.

Students are frequently challenged when interpreting and constructing visual images in the STEM fields. Common difficulties students face involve (Åberg-Bengtsson, 2006; Coleman & Dantzler, 2016; Glazer, 2011; Kress & van Leuween, 1996; Lemke, 1998b; McTigue & Flowers, 2011; Rau, 2017; Roth & Bowen, 2003):

- The polysemy of some visual conventions used in the STEM visual language. For example, arrows can signify vectors, direction, change, or sequence;
- The slope-height confusion (i.e. being unable to visually distinguish between the rate of change and particular values of a variable, see Glazer, 2011, Figure 1);
- Reading a graph as a realistic image, or as a map instead of reading it as an abstract, symbolic representation, or uncritically reproducing shapes and forms (see Figure 8);
- Seeing a graph as an array of distinct points, instead of a continuous line (e.g. when students follow a ‘connect the dots’ strategy instead of finding the best-fit trend line);
- Uncritically memorizing and imitating graph shapes and forms without paying attention to selecting the appropriate variables, or correctly positioning the variables on the x-y axes (Figure 8).

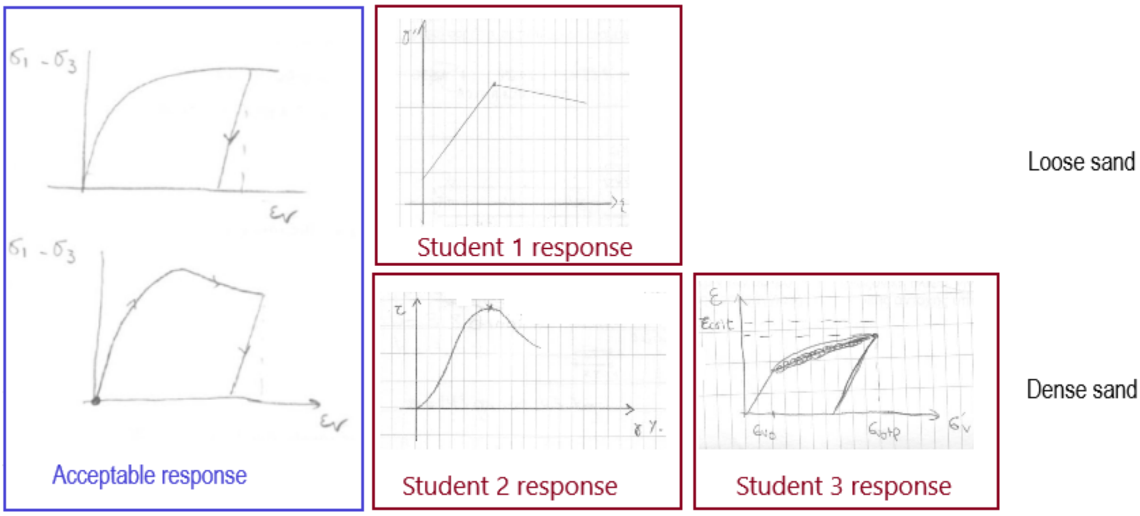

Figure 8. A problem asking civil engineering students in a Soil Mechanics class to draw a stress-axial strain diagram resulting from a triaxial test with a loose or dense sand upon loading and unloading. Students’ responses reveal superficial memorization and imitation of shapes and forms (Student 1), confusing conditions (loose vs. dense sand, Students 1 and 3), using inappropriate variables (all three students), and shifting variable positioning between the x-y axes (Student 3)

Another factor that could hamper students’ understanding of visual images is that they introduce an additional layer of complexity in multimodal texts. Reading and interpreting images requires processing each image individually and interrelating it with the verbal text and with other images on the page. These elements should be considered as parallel, interweaved meaning-making devices

(Coleman & Dantzler, 2016; Kress & van Leuween, 1996). Students may be selective as to which information is essential in visually complex layouts. For example, students tend to focus on particular elements on a page based on their salience, or familiarity (e.g. a realistic image), thereby disregarding other, and equally essential information (Avgerinou & Pettersson, 2011; Matusiak et al., 2019; McTigue & Flowers, 2011). Students' previous knowledge about the depicted concepts is a key factor for interpreting images. Students with sufficient knowledge of the domain can successfully locate conceptually relevant components in different representations. In contrast, students with inadequate previous knowledge tend to focus on superficial features of images, e.g. to see graphs as pictures (Figure 8), thus failing to locate their underlying similarities and to relate them appropriately (Cook et al., 2008).

In summary, not all visual images are appropriate for STEM education. Visual representations that have been found more effective in communicating STEM-related concepts, possess one or more of the following qualities (Avgerinou & Pettersson, 2011; Byrd, 2018; Carifio & Perla, 2009; McTigue & Flowers, 2011; Rau, 2017):

- They involve some level of realism in depicting STEM entities;
- They highlight the crucial components of phenomena, while concealing redundant information and preventing informational 'noise';
- They comprise labels for crucial entities, explanatory captions, or other reading aids that clarify the intended meaning and promote the appropriate -among several possible- interpretation;
- They add complementary information in a text, expanding and clarifying the meaning expressed verbally and enabling students to connect the verbal with the visual mode in a coherent whole.

Such criteria are essential for selecting and designing visual representations of STEM-related knowledge appropriate for each educational setting. Nevertheless, being more or less comprehensible is not entirely an inherent feature of an image. As already mentioned, this significantly depends on the reader's prior knowledge and experience with similar images. When students 'read' specialized STEM visual images intuitively, they often rely on specific expectations, which possibly leads to misinterpretations of the images and misconceptions about the knowledge at stake (Åberg-Bengtsson, 2006; Avgerinou & Pettersson, 2011; Cheng et al., 2001; Glazer, 2011; Lemke, 1998b; McTigue & Flowers, 2011; Roth & Bowen, 2003; Rau, 2017). Besides, constructing visual images in the context of STEM education is even more demanding than reading pre-constructed ones. Students may leave out important details in their visual constructions, or fail to use appropriate visual codes for representing STEM knowledge. This in turn could impede their cognitive progress. These findings indicate that the tenets of visual literacy should be explicitly taught in the context of STEM education (Britsch, 2013).

5 Scaffolding students' STEM visual literacy

The development of STEM-VL presupposes that students are systematically engaged in activities of reading and interpreting visual images in the context of investigations involving data selection, graph construction and argumentation based on visual information. Visual representation of experimental data in the form of tables, diagrams, etc., allows students to reflect on STEM-related concepts, exchange and clarify meanings, while it contributes to the acquisition of specialized conventions of scientific visual language (Britsch, 2013; Glazer, 2011). Such practices 'scaffold' students in using visual representations effectively. They entail social interaction, collective mental activity and guidance by experts. Through interaction with more visually literate individuals, students first observe how these individuals use visual representations to deduce the important visual elements, and finally acquire the STEM 'visual language' (Åberg-Bengtsson, 2006; Rau, 2017).

To promote these competences, teachers should explicitly aim at the development of their students' STEM-VL. Interpretation and construction of visual images, students' familiarization with different kinds of visual representations and with the visual conventions they integrate, are considered to be good teaching practices (Gonitsioti et al., 2013). For instance, supporting students in determining the similarities between a laboratory experiment (Figure 9) and a diagram (Figure 10) and subsequently asking them to construct similar diagrams themselves (Figure 11), would be a valuable learning experience for them and a documentation of their learning for the engineering teacher.

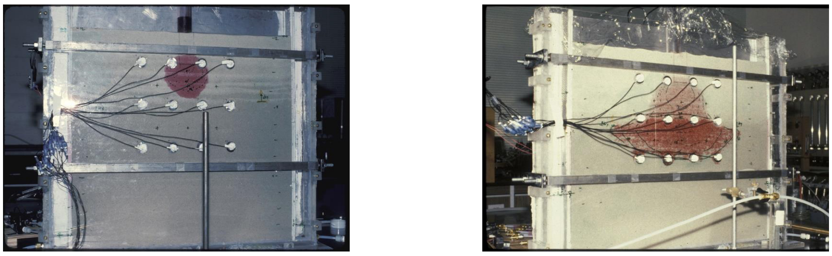

Figure 9. **Laboratory experiments simulating spills of a light nonaqueous phase liquid (LNAPL) (Pantazidou, 2020: used with permission)**

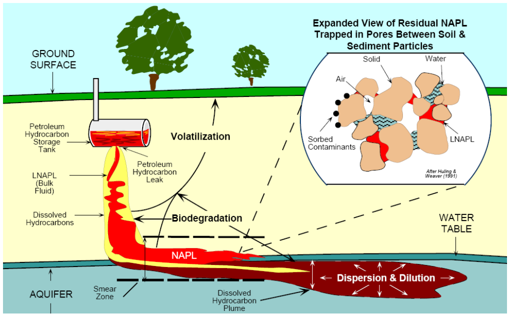

Figure 10. A schematic diagram (a hybrid) of a LNAPL spill (US Environmental Protection Agency, 1999)

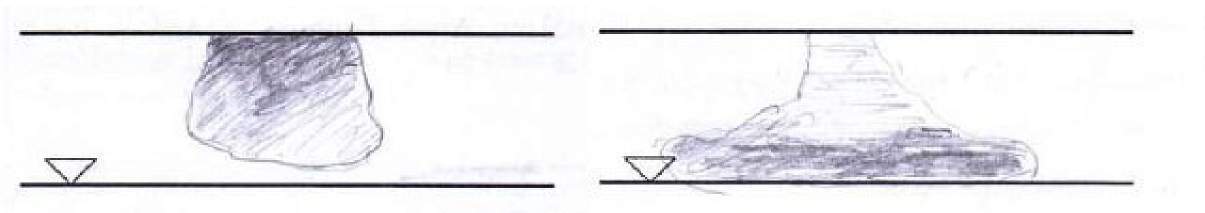

Figure 11. Civil engineering student's schematic diagrams of the area contaminated by the LNAPL shortly (left) and long (right) after the LNAPL spill

As already mentioned, understanding STEM concepts often requires that these be addressed by means of multiple (visual) representations. In this case, students' learning would need to be scaffolded in 'translating' one image to another (Ainsworth, 2008). A common practice in this case is providing students with different images and explaining their similarities and differences in terms of form and information involved. The indicated scaffolding strategy would be to emphasize how different visual representations highlight different aspects of the same entity, to discuss the relevant advantages and disadvantages of each representation in a specific context and to stress the importance of selecting the appropriate representations (Cook et al., 2008; Glazer, 2011; McTigue & Flowers, 2011). Other potentially helpful strategies could involve moving between different levels of difficulty in terms of the specialization of the visual code, or the scientific thinking competencies required to master each visual image. For example, introducing images with varying degrees of realism and abstraction (e.g. a photograph, a hybrid and a diagram of the same phenomenon, see Figures 9, 10 and 11) would be expected to support students in making apposite connections between reality as perceived and its increasingly elaborated representations. Similarly, the advancement from narrative images depicting events or processes to classificational or analytic images would expand students' visual resources related to a variety of thinking competences. Discussion about what lines, symbols, or different color codes signify in an image are extremely helpful in initiating students in the STEM visual language (Åberg-Bengtsson, 2006; Carifio & Perla, 2009; Gonitsioti et al., 2013; Koulaidis et al., 2002; Kress & Van Leeuwen, 1996).

Lastly, having students construct images is another effective learning and problem-solving strategy, enabling them to master scientific concepts and to develop higher order competences. Furthermore, when asked to introduce visual representations in their multimodal texts, students make complex semiotic selections, which document their learning process. Research suggests that students' visual constructions should be recognized explicitly and equally with verbal productions as indicators of their progression in STEM-related disciplines (Ainsworth et al., 2011; Britsch, 2013; Glazer, 2011; Jewitt, 2008; McTigue & Flowers, 2011).

6 Implications for teaching and research

Acknowledging the value of visual representations in STEM education brings about specific demands from teachers. These involve (i) selecting the appropriate multimodal texts and contexts that support learning; (ii) guiding students while navigating these texts with strategies and practices like the aforementioned; and (iii) explicitly asking students to construct and use visual images in the context of STEM education (Ainsworth et al., 2011; Jewitt, 2008; Lemke, 1998b). Furthermore, students' images are valuable tools for assessing their knowledge and their level of STEM-VL. Thus, teachers would be expected to introduce coherent, comprehensive assessment criteria to evaluate students' visual images and multimodal texts (Ainsworth et al., 2011; Britsch, 2013; Jewitt, 2008).

However, research (McTigue & Flowers, 2011) indicates that teachers are not very systematic in selecting and analyzing visual images. The opportunities they provide to their students to develop an understanding of STEM visual language are limited. This could be expected, since teachers are not trained on topics of visual literacy. Therefore, they are not aware of the conventions and particularities of the STEM visual language necessary to assess the visual meanings conveyed by teaching material and students' constructions. This lack of knowledge evidently prevents teachers from adopting practices that 'scaffold' their students' STEM-VL (Glazer, 2011). Teachers at all levels would therefore need to be appropriately trained to meet this challenge. First, teachers' training could aim at raising their awareness that images are an integral part of students' learning. Second, it could also provide teachers with criteria for selecting and evaluating appropriate visual images as conceptual and STEM-VL scaffolds. Third, teachers' training should provide them with assessment frameworks for estimating students' STEM-VL and taking the necessary steps to improve it (Bowen, 2017; Britsch, 2013; Kędra, 2018; Matusiak et al., 2019).

As already pointed out, the development of STEM-VL is a multidimensional research area. Despite the argumentation calling for more frequent and more systematic student engagement with visual images, several STEM-VL issues require more investigation. More specifically, more research is needed on how students integrate different semiotic modes (e.g. verbal language and images) to construct meaning; the transfer of representational competencies from one conceptual field (e.g. physics) to another (e.g. engineering); the optimal number of different (kinds of) images to be used when teaching with multiple representations, according to the conceptual domain and students' knowledge level; how STEM-VL could be included in STEM curricula and in guidelines for teachers (Ainsworth et al., 2011; Byrd, 2018; Glazer, 2011; Lemke, 1998b; Rau, 2017; Trumbo, 1999). This list is only indicative of the scope and interdisciplinarity of STEM-VL as a research field. The overarching goal of STEM-VL research is to empower all students as future engineers or scientists, but also as citizens, to participate successfully in an increasingly complex, visually saturated environment (Kędra, 2018).

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Invited author's bio

Vasilia Christidou, Aristotle University of Thessaloniki, Greece

Dr. Vasilia Christidou is Associate Professor at the School of Early Childhood Education, Aristotle University of Thessaloniki, Greece. She has graduated from the Physics Department at the Aristotle University of Thessaloniki and received her PhD in Education from the University of Patras, Greece. Her field of specialization is science education. She has served as Quality Monitor for the implementation of the OECD PISA program in Greece. She has also served as an expert evaluator for the European Commission (FP6 and FP7 'Science in Society'). Her current research interests include teaching and learning in science, the promotion of Public Understanding of Science, the process of recontextualization of scientific texts addressed to non-experts, science communication, and gender issues in science education.

Developing Soft Soil Engineering Skills Using “Class B” and “Class C” Predictions

M. Karstunen, G. Birmpilis & J. Dijkstra

Chalmers University of Technology, Gothenburg, Sweden
minna.karstunen@chalmers.se, georgios.birmpilis@chalmers.se, jelke.dijkstra@chalmers.se

ABSTRACT: The calculation of one-dimensional consolidation settlement is a classic geotechnical problem that involves many steps with associated judgement. To give students an opportunity to develop soft-soil engineering skills, we developed a coursework assignment with “Class B” and “Class C” type of predictions of a test embankment on soft clay, starting from real data. “Class B” predictions allow students to deal with uncertainty in input data, while “Class C” predictions enable the students to appreciate the main sources for errors in their analyses. In this paper, we describe the assignment, and the changes made over the course of three years. Furthermore, we analyse the results for selected student cohorts and compare them with the predictions by professionals. The results show that accurate consolidation analysis is not trivial. It is encouraging though that many of the students performed as well as the professionals.

Keywords: soft clay, consolidation, embankment, Class C prediction, Asaoka’s method

1 Introduction

The calculation of one-dimensional (1D) consolidation settlements is a classic geotechnical problem, which is included in every geotechnical engineering textbook and syllabus. Consolidation analyses are particularly important in areas with extensive deposits of soft soils. It is most often embankments for linear infrastructure, e.g. roads, railways, flood protection embankments and tailing dams, for which the analyses of the consolidation settlements are relevant. The problem of consolidation under embankment loading can be considered as a 2D plane strain problem, which is often simplified to 1D, considering vertical settlements only. For preliminary design, and design in rural areas with no sensitive structures in the vicinity of the planned embankments, 1D analyses often suffice.

One-dimensional consolidation analyses for a real embankment involve many steps with assumptions and judgment that are subjective. The latter is not apparent from most textbooks. Assuming the site investigation and laboratory testing have been planned appropriately, and the necessary data are available, there are several steps in 1D consolidation analyses. These include e.g. dividing the compressible deposit into representative layers (initially based on index properties, further refined based upon other laboratory and site investigation information prior geological knowledge), identifying the level of the water table and drainage conditions, determining the relevant model parameters from laboratory test results, calculating the initial stress distribution and the stress increment from the embankment loading as a function of depth, calculating the total consolidation settlement, and finally the rate of settlement. Each stage introduces subjectivity, uncertainties and possibilities for errors. In particular, the interpretation of model parameters from the laboratory test results benefits from experience on similar soil conditions.

For the reasons above, we developed a coursework assignment that gives the students an opportunity to develop soft-soil engineering skills using “Class-B” and “Class-C” type of predictions. “Class B” predictions are blind predictions made during construction with available data, with no knowledge of the field measurement results, while “Class C” predictions are improved predictions with the aid of field observations. “Class B” predictions allow the students to deal with uncertainty, while “Class C” predictions enable to understand the main sources for errors in the analyses (Lambe 1973). In the following, we introduce the case (additional materials can be made available electronically upon request by interested instructors), analyse the results for selected student cohorts, and describe the changes we made over the three years in question. Finally, we compare the predictions by the students with the "Class A" predictions by professionals, made before the construction.

2 Background

The starting point for 1D consolidation analyses is oedometer test results. The way 1D consolidation tests are performed, however, differs from country to country. Most common are Incremental Loading (IL) oedometer tests, which can provide the parameters needed to make predictions that match the field measurements reasonably well. However, the way the load steps are chosen for IL test, the methods for sampling, as well as the quality of sampling and testing may vary. In addition, in some countries, such as Sweden, settlement analyses are largely based on continuously loaded oedometer tests (generally much faster than IL tests), referred to as Constant Rate of Strain (CRS) tests. As only the rate of displacement is controlled, the true strain-rate (by strains here we mean natural strains) increases during the CRS test, and it also takes time for the system to ramp up to the target displacement rate. The higher the strain-rate, the higher the apparent preconsolidation pressure. Thus, the preconsolidation pressure needs to be somehow corrected for strain-rate effects, to yield values that are similar to those from IL tests. The locally derived corrections, such as those used in Sweden (see Sällfors 1975), cannot be generalised for all clays, because the strain-rate susceptibility of clays varies depending e.g. on sensitivity and organic content. Due to the effects of aging (see e.g. Bjerrum 1967) and cementation (e.g. Leroueil & Vaughan 1990) most natural soft soils are lightly overconsolidated, and thus preconsolidation pressure is an important parameter. Finally, the methods for calculating the magnitude of the consolidation settlement (i.e. how to represent the stress-strain response) also vary from country to country.

The rate of consolidation is often calculated with Terzaghi's (1925) 1D consolidation theory, accounting for the distribution of excess pore water pressures by Terzaghi & Fröchlich (1936). The increasing internationalisation of the student body necessitates that geotechnical education covers more than just the locally used methods for consolidation analyses. The students need to appreciate that there are multiple ways of doing the analyses, and furthermore there are a lot of uncertainties involved when the theories developed for "ideal soils" are applied to natural soft soils. Geotechnical textbooks rarely present real soil data, and in the examples included, the model parameters are derived from "ideal" data, which fully conform with the theories used. Examples of settlement analyses tend to use fixed values for model parameters, giving the misleading impression there is one exact, "correct", solution. Issues like sample disturbance, and its effect on the measured stress-strain curve, and the apparent preconsolidation pressure, are addressed in only a few textbooks, such as Barnes (2016).

It is important for future geotechnical practitioners to understand how the theories are applied to real data, and also to appreciate how error-prone, and inaccurate, the consolidation analyses can be in practice. The settlement calculation competition for the Haarajoki test embankment in Finland (Lojander & Vepsäläinen 2001), and most recently the Ballina embankment challenge in Australia (Kelly et al. 2018), demonstrate that even if the analyses are done by the most experienced academics and practitioners, the errors in the predictions of consolidation settlements can easily be $\pm$20%. The errors can be even larger, if the practitioners are not used to dealing with sensitive clays, which practically exhibit "a collapse settlement" when the preconsolidation pressure is exceeded. This was the case in Haarajoki test embankment. Furthermore, Kelly et al. (2018) show that the scatter is most significant for "Class A" predictions. Field monitoring can significantly improve the predictions during construction time.

The natural clays found in Scandinavia were formed during and after the last Ice Age, when large parts of the Northern Hemisphere were covered with glaciers. The glacial meltwaters, heavily laden with sediments, discharged to glacial lakes and seas. In particular, the fine-grained sediments from the Yoldian and Littorina sea stages of the Baltic Sea region (see Björk 1995), were deposited in brackish or very salty water, which led to an open structure with large water contents. These deposits subsequently surfaced from the sea due to the isostatic uplift and were exposed to leaching. Consequently, these post-glacial clays have an open structure that is now metastable, and often exhibit significant sensitivity. As a result, their response under one-dimensional loading does not follow the response typically shown in textbooks. Figure 1 combines the results from multiple IL oedometer tests of a sensitive Finnish clay, Vanttila clay, plotted in semi-logarithmic scale. On the left in Figure 1 we have plotted the vertical effective stress vs. void ratio *e*, and on the right the creep index (secondary compression index) $C_{\alpha e}$ (defined as $-\delta e/\delta \log t$, where *t* is time). The black stars correspond to the intact samples of natural clay, taken with piston samplers, and the red squares are the results for the same clay after remoulding at the same water content, and subsequent reconstitution to the in-situ stress level. The sensitivity (S_t) of the clay is above 50 (Karstunen & Koskinen 2008). Only the reconstituted samples exhibit a constant compression index C_c as found in textbooks. The apparent C_c values of the natural clay are changing with the stress level, and the same applies to the creep index. In contrast, the swelling/recompression index C_s is approximately the same. The C_c values are the highest just after yield (see dashed black line in Fig.1), and this coincides with the effective stress level for the highest apparent creep rates ($C_{\alpha e}$ values in Fig. 1). Thus, when performing the consolidation analyses of natural clays, it is important that the oedometer stiffness used corresponds to the appropriate stress range. In practice, if C_c is used, the value should typically be determined from the steepest part of the slope, just after the yield (as indicated by the dashed black line in Fig.1). The consequence of the large C_c value is that the results of the 1D settlement analyses are very sensitive to the value of the apparent preconsolidation pressure, which can also be affected by sample disturbance.

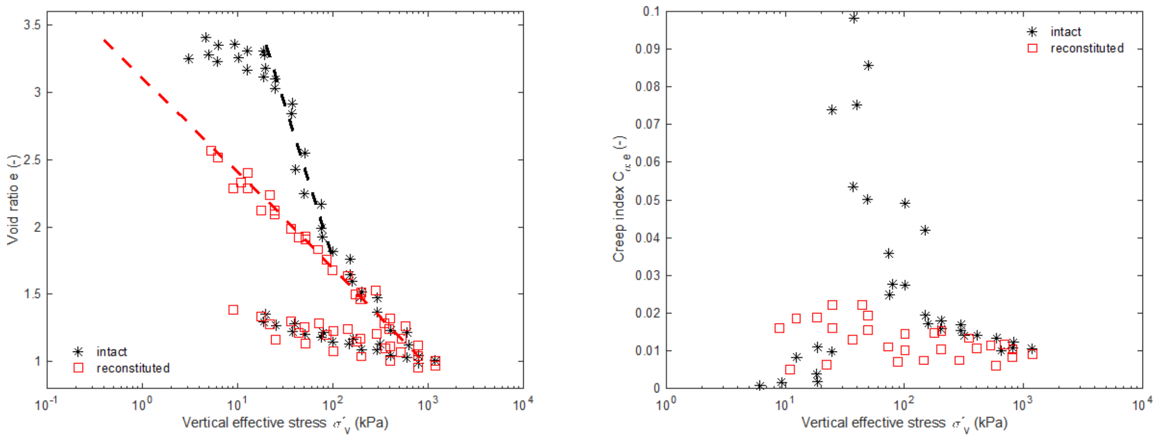

Figure 1. 1D response of intact and reconstituted Finnish sensitive clay (data from Yin et al. 2011)

The coefficient of (vertical) consolidation, c_v, also varies with effective stress level, with the lowest values just after yield. Particularly for layered deposits, the c_v values in the field can be magnitudes higher than the values measured in the laboratory, see e.g. Baligh & Levadoux (1986) and Leroueil (1988). Furthermore, IL tests usually suggest systematically lower values than CRS tests. Combined with uncertainties in the drainage conditions in the field, consolidation analyses are not simple. Thus, we wanted to develop a coursework assignment where we provide students with field monitoring data, as one would get during construction of an infrastructure project, in addition to laboratory data. This would enable the students to have a pedagogically important feedback loop, which hopefully highlights the most likely sources for the errors in their predictions, whether it is their prediction of the total settlement or the rate of settlement.

3 Implementing a design project

3.1 Purpose of the design project

Our pedagogical vision is to educate students in the relevant theories and methods for soil mechanics and geotechnical engineering, with the ability to confidently apply these in a practical context, using real data. Given our geographical location, the focus is on soft natural clays. The coursework assignment, involving consolidation analyses of a real embankment, was developed as a response to the student expectations: the course evaluation in 2014 suggested that the Year 4 MSc course was too theoretical and abstract. The students wanted to have the opportunity for a realistic application of their knowledge, similarly to our BSc level courses. Our expectation was that by starting from real experimental data and adding a feedback loop enabling the students to assess where they might have gone wrong, the students would develop valuable skills in soft clay engineering.

The coursework assignment was run in 2015-2019 at Chalmers University of Technology, Sweden, combining “Class B” and “Class C” predictions. Initially, the assignment was included in an optional Year 4 MSc course taken by students from two MSc programmes: (1) Infrastructure and Environmental Engineering and (2) Structural Engineering and Building Technology. The typical class size was about 100 students. In 2017, as part of our new degree programmes (i.e. BSc in Civil Engineering and MSc in

Civil and Environmental Engineering), the assignment was moved to Year 3, to an optional course Hydrogeology and Geotechnics, with about 70-80 students. In both cases, the Chalmers students had the knowledge from Year 1 Engineering Geology (7.5 ECTS) and Year 3 Geotechnics (7.5 and 6 ECTS, in the “old” and “new” degree programme, respectively), taught in Swedish. Year 3 Geotechnics covers the CRS test-based consolidation settlement calculations used by industry in Sweden. The MSc students had much more variable background: about 50% were Chalmers students, 33% Erasmus/exchange students from Europe and 17% international students from all over the world, the latter including some students with no geotechnical courses as part of their previous education. With these few exceptions, the concept of consolidation settlements of clays is known to all students.

3.2 Selecting a case study

We wanted an embankment on soft sensitive clay without any ground improvement, with access to site investigation data and laboratory data in a digital format, so that we could supply the data in a format that was suitable for our students. Furthermore, there had to be a sufficiently long time-series of settlement measurements enabling a feedback loop. These requirements were satisfied by the Haarajoki test embankment in Southern Finland, which was built in 1997 by the Finnish Road Administration to evaluate the long-term settlements and the changes in the undrained shear strength as a function of time (Vepsäläinen et al. 2002).

Haarajoki embankment has been used to test the accuracy of different constitutive models and modelling approaches (e.g. Yildiz et al. 2009; Amavasai et al. 2017) and was also used for an international “Class A” prediction competition (Lojander & Vepsäläinen 2001). The latter involved predictions with conventional methods and numerical methods, considering also a section on vertical drains installed over half of the length of the embankment. Figure 2 shows the results, for the section with no ground improvement, for vertical settlements directly below the centreline (data from Lojander & Vepsäläinen 2001). The predictions are compared with two years of measurements. The best prediction, which is rather accurate, was made by a team with local knowledge. Some participants seem to have included also the immediate settlements. The large scatter in the predictions is associated with inexperience with sensitive clays of some of the predictors (who assumed the soil to be normally consolidated). We were thus curious to see how our students’ predictions relate to the professionals, after the guidance we give as part of the lectures and tutorials.

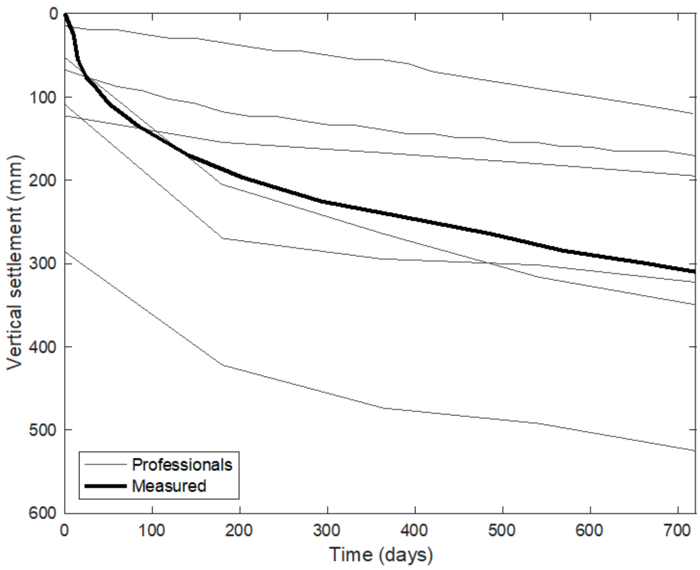

Figure 2. Measured vertical settlements of Haarajoki test embankment and “Class A” predictions made by geotechnical professionals (data from Lojander & Vepsäläinen 2001)

Haarajoki test embankment (Fig. 3) about 45 km North-East from Helsinki was built on a deposit of about 20 m of soft sensitive clay about 45 km North-East from Helsinki. At the bottom, there is about three meters of highly permeable glacial till (sandy moraine) on top of the bedrock, and just below the surface there is a 2 m thick dry crust, linked with the seasonal variation of the groundwater table. Piezometer measurements on the site suggest that on average, the water table is approximately at the ground surface. The clay has a sensitivity (the ratio of the intact undrained shear strength to the remoulded undrained shear strength) S_t = 25 at the top, increasing to S_t = 50 towards the bottom. The dimensions of the test embankment are given in Figure 3. In total, the embankment is 100 m long, with stabilising berms on both sides. We only consider the part of the embankment (50 m long) on natural clay (i.e. not the section with vertical drains). The test embankment was built over a period of 35 days in multiple steps (see e.g. Amavasai et al. 2017), but given the low hydraulic conductivity, the students are told to assume instantaneous loading. Most natural clays exhibit tendency to creep, and the students are aware of the role of secondary compression. Modelling creep was not explicitly included in the student assignment in order to keep the workload manageable. The creep effects are, however, implicitly included, given the *e* vs. effective stress plots represent the *e* values after 24h, as is the industry practice, rather than at the end of consolidation. The task for the students is to predict the vertical settlement as a function of time in point A, just under the centreline.

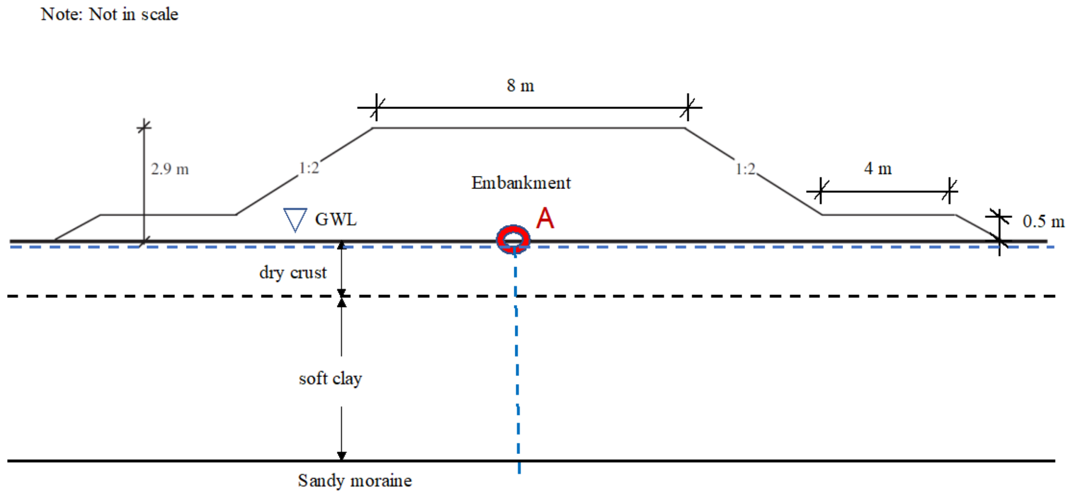

Figure 3. Simplified cross-section used for settlement prediction (not in scale)

3.3 Materials provided to the student

The cross-section of the embankment (Fig. 3) was provided to the students by giving them a copy of the actual construction drawings of the relevant cross section. That included the site investigation data, consisting of field vane tests, CPT tests and Swedish weight sounding tests. We also explained how the tests are conducted, and what for. The students were also provided with basic index properties (see e.g. Amavasai et al. 2017), i.e. water content, organic content, undrained shear strength from fall cone, void ratio, unit weight and sensitivity. Based on all these, the students can confirm the approximate symmetry of the problem, estimate the thickness of the dry crust and compressible layer, whilst the data on index properties enables them to divide the soft clay into representative layers for the analyses, to be confirmed by other laboratory data. An example of how to do the layer division was done in the class, using another deposit as an example.

We digitised all laboratory data available to the contestants of the original settlement calculation competition. The students were provided with IL test data (void ratio vs. vertical effective stress) in Excel format for determination of preconsolidation pressures and stiffnesses. The results were also plotted in semi-log scale for direct use. CRS data (plotted in terms of coefficient of consolidation vs. vertical effective stress), see Figure 4 as an example, was provided to reduce the routine work associated with determination of c_v. For the MSc students we provided all data, i.e. 27 IL oedometer tests and 14 CRS tests. For Year 3 students, who also had other course assignments, we reduced the amount of data by selecting only 9 IL tests and 6 CRS tests, effectively cutting out the tests on samples that were deemed to be most disturbed. The project consisted of two parts, as described in the following.

Students were also provided with an Excel template for returning the result. They needed to report the time-settlement curves for circa 1500 days, as well as the estimates for the total settlement, plus justifications, such as the interpretation of in situ stresses, preconsolidation pressure etc. The students were processing the data and doing their analyses in groups of max 3 students. After we got the submissions for Part 1 of the project, we provided the measured settlements at the centreline, and 4 and 9 m off the centreline. We used the 3 years of measurement data available in Vepsäläinen et al. (2002). The measured settlement under the centreline was 370 mm after 3 years. When compared to the estimated final settlement (1200 mm), derived by Länsivaara (2001) using the so-called settlement potential method (including of course also creep and 2D effects), or 2D analyses with the advanced anisotropic creep model Creep-SCLAY1S by Amavasai et al. (2017), this corresponds to a degree of consolidation of around 30% only in terms of settlements. However, in terms of the excess pore water pressure dissipation, the actual degree of consolidation after three years is closer to 60%. So, there is much creep, which means that the assignment is not ideal.

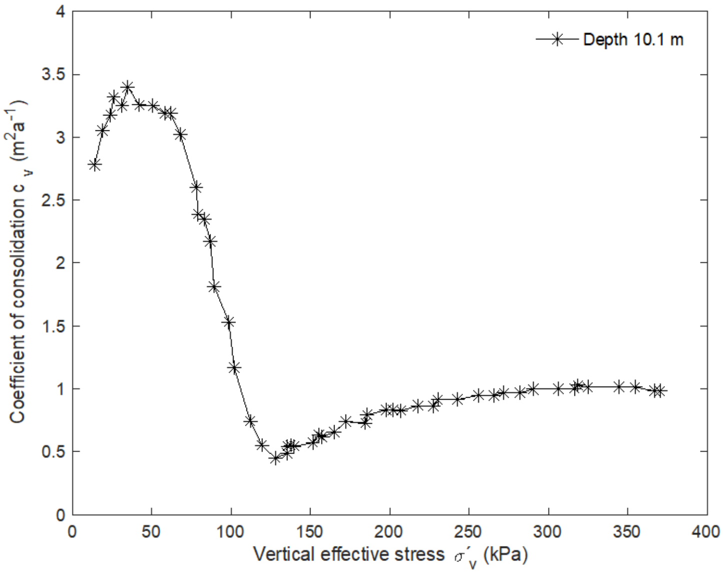

Figure 4. Example of CRS data provided to the students

In Part 2 of the project the students were asked to use Asaoka's graphical method (Asaoka 1978) on the field measurements. The method was introduced in the lectures. Asaoka's method requires field measurements of settlements as a time series, from which settlement values are determined for times t, t+Δt, t+2Δt, etc. The final (total) settlement is estimated by cross-plotting pairs of consecutive settlement values. It is based on the expectation that after a sufficient time, the measurements at two consecutive time steps will be the same. The field value for the coefficient of consolidation, c_v, for the deposit as a whole is calculated from a tangent drawn to the curve in the previously mentioned graph and taking into account the form of the differential equation describing consolidation settlement. With their estimates of (a) the final settlement and (b) the field values of c_v, Asaoka's method enables the students to reflect what (in most cases) had gone wrong in their predictions. According to Länsivaara (2001), Asaoka's method is not the best in a creeping deposit, but the alternative methods that were also introduced in the class are not internationally as well known. In the following, we analyse the "Class B" results for selected cohorts, describe the changes we made, and also compare with the "Class A" predictions by professionals.

4 Results

4.1 MSc cohorts 1 & 2

The students in MSc cohort 1 (in 2015) could use any method they wanted. From 2016 onwards we imposed the settlement calculation method that separates the compression and swelling (or recompression) indices. This requires the determination of the preconsolidation pressure and has thus a better linkage with the Modified Cam Clay (MCC) -type of models the students will use in Year 5 (such as MCC (Roscoe and Burland 1968) and the Soft Soil model in Plaxis FE code). As a first comparison, Figure 5 presents the predicted and measured time series of the vertical settlements directly below the embankment by the two MSc cohorts, i.e. the "Class B" prediction. As opposed to the Class A predictions in Figure 1, now 1483 days (4 years) of measurements are available. Even though two cohorts are shown, for cohort 2 only a third of the data was readily available for plotting.

MSc cohort 1 has a larger number of outliers in the results than MSc cohort 2. The scatter is largely related to the freedom MSc cohort 1 had in selecting their calculation method. The time-series indicate that both the estimated final settlement and the rate of consolidation were highly inaccurate for a large number of students. Interestingly, the most accurate prediction in MSc cohort 1 did not use any equation or derived stiffness properties. Instead, the total vertical strain was determined using, for each layer, the oedometer compression curves closest to the centre of the layer, and the corresponding stress increment at each depth (graphical interpretation) and summing them up for all layers. This circumvents the need for the evaluation of consolidation parameters that are error-prone, and it also was less effort for the students. Most students, however, used one of the methods taught during the course and practised in the tutorials.

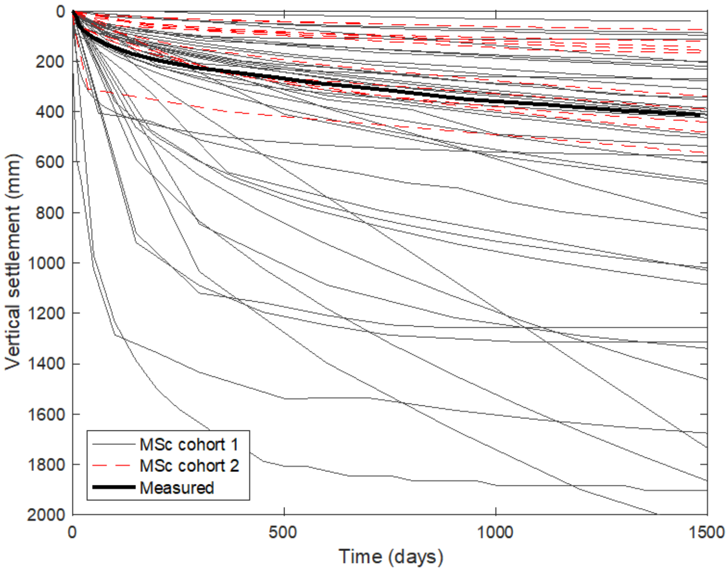

Figure 5. Measured time series for the vertical settlements directly below the embankment at the centreline and predictions made by 2 cohorts of students in the MSc programme at Chalmers

For Part 2 of the project, 1st cohort of MSc students really struggled with Asaoka's method, which included two different back analyses: (a) amount of settlement and (b) rate of settlement. Thus, for the following years, the lecture on Asaoka's method was complemented with a hands-on tutorial example, using the data from Skå-Edeby test embankment (Larsson 2007).

As already mentioned, following the first year, and in order to have alignment with the courses to come, the MSc cohort 2 was instructed to use only the method based on C_c, C_s and preconsolidation pressure. This helped to align course materials, related to the geological and anthropogenic processes affecting the apparent preconsolidation pressure in natural soft soils, with the assignment. Furthermore, it transforms the problem-based nature of the assignment into a project-based element. These changes reduced the scatter (as seen in Fig. 5), but also introduced an underprediction bias in the results, as discussed in the following paragraph. For further analyses the results are re-plotted in Figure 6 as a histogram, which plots the frequency of occurrence for 10 bins and three data series: MSc cohort 1 & 2 and the BSc cohort 1. All available data for the settlements at the end of the measurement period have been processed by subtracting the measured value, so the deviations from measured are shown in Figure 5. A time window between 1483 and 1500 days has been used to determine this end value.

The most striking finding is that prescribing the method resulted in a systematic underprediction of the settlements by MSc cohort 2. Examination of the reports indicates that this underprediction is linked in most cases with defining C_c as the average for the entire effective stress range, and/or overestimation of the apparent preconsolidation pressures. Furthermore, it shows the rather close predictions of almost half of the MSc cohort 1 falling within +/- 200 mm or +/-50% of the measured settlements (the bin width is 200 mm).

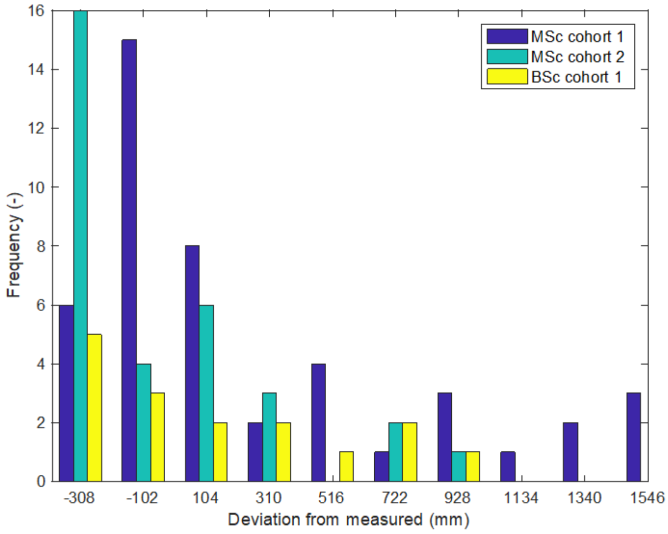

Figure 6. Deviation between predicted and measured (411 mm) vertical settlements below the embankment at the centreline after 1483-1500 days

The data for the results of Part 2 of the assignment, i.e. the use of Asaoka's method to improve the initial predictions, was much harder to analyse (and to mark). In short, the mediocre students simply 'fitted' the data by random alterations of the parameters, and the good students left things unchanged. This was partly related to our seven-week intense teaching periods, which means that the students run out of time at the end of the course. In the second round for MSc cohort 2, after introducing a separate additional tutorial on the use of the method, the results of Part 2 were more reflective, as was our intention. When in industry, the students need methods for assessing how consolidation progresses in the field. Asaoka's method is only one of the methods taught in the course that can be used for this purpose. The pedagogical implications for the observations will be further discussed in Section 5.

4.2 BSc cohort 1

Figure 6 already indicates that BSc cohort 1 performed similarly to MSc cohort 2, with emphasis on under- rather than overprediction, and a much narrower spread than MSc cohort 1. In that aspect, reducing the available laboratory data seems to have similar effect for both MSc 2 and BSc 1 cohorts.

Studying the time series in Figure 7 may give the impression that uncertainty arises in the determination of the coefficient of consolidation (from averaging CRS data for each depth over the full profile, and/or from the assessment of the drainage conditions at the field). To further evaluate this interpretation, a histogram of the predicted final settlements is presented in Figure 8. Given the slow processes, there is no measurement data available for this estimate. As already mentioned, the best estimate for the final settlements is 1200 mm (Länsivaara 2001; Amavasai et al. 2017). Many students are surprisingly close to this magnitude (1200 mm ± 100 mm). The fact that the estimate for the magnitude of the settlement is on average reasonable, reinforces the interpretation that establishing an estimate for the coefficient of consolidation, as an average for the whole deposit is difficult. This cannot solely be attributed to the students, as it is an inherent limitation of the methods used. Santamarina (2015) argues for the use of numerical methods that supersede the simplified single point analyses advocated by most teachers and textbooks.

5 Pedagogical reflection

In addition to the industry's need for graduates able to perform engineering designs with natural soils, as described in the introduction, there were pedagogical motivations for the coursework development as well. First, the course needed changes to improve the engagement of the indifferent middle group, i.e. the efficient students who design their study to pass the course with minimal effort, maximum effect in terms of a grade and minimal retention of knowledge (e.g. Marton & Säljö 1976). A teaching instrument that brings the students closer to the engineering practice will help (and was requested by students in prior years). The most likely tool for this seems to integrate a problem-based learning element in the course. The expected outcome is that, when attained, problem-based learning should help students to have a longer retention of their knowledge and an idea of the relevance of the material to the engineering practice (Beers & Bowden 2005). Furthermore, project work will help the student understand what real engineering is about, i.e. without the certainties that you do not find in a textbook assignment.

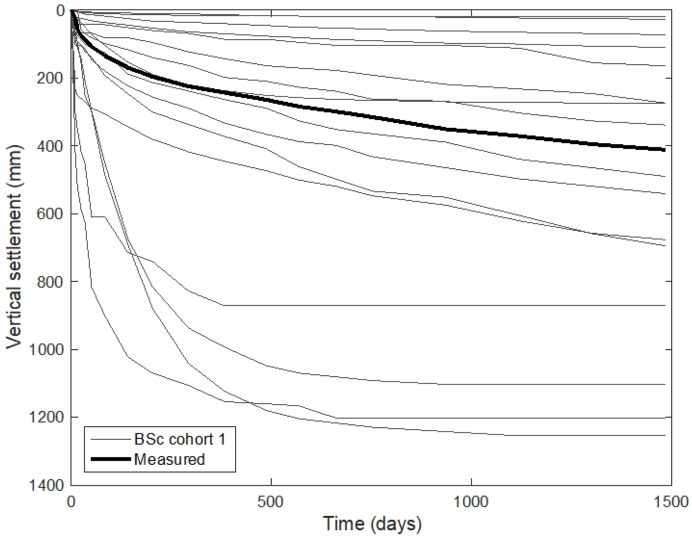

Figure 7. Measured time series for the vertical settlements directly below the embankment at the centreline and predictions made by Year 3 BSc cohort at Chalmers

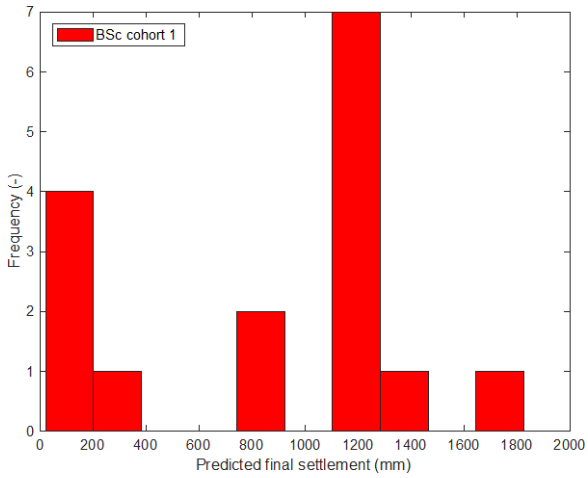

Figure 8. Histogram of predicted final vertical settlements directly below the embankment at the centreline by Year 3 BSc cohort at Chalmers

The first implementation of the project work, i.e. MSc cohort 1, proved to be closer to problem-based learning, where the students develop knowledge during the project. Not only is this hard for an engineering project, it also requires students to be trained for project-based learning: independence, group work, interpersonal skills, etc. (Woods 1996). In conventional Civil Engineering programmes, such as the one at Chalmers, students are not explicitly trained to develop such skills. Furthermore, there was not as much alignment between the lectures, tutorials and the activities in the prediction project as would be pedagogically effective (Biggs 2014). It turns out that for complex tasks in engineering education, which the project inevitably represents, problem-based learning is unsuitable (Perrenet et al. 2000; Mills & Treagust 2003).

In the subsequent implementation of the project, more guidance and prior knowledge was developed following constructive alignment practices, linking taught material and schedule with project deliverables, as well as adding an additional tutorial on Asaoka's method. Whilst this reduced the scatter in the results (MSc cohort 2), it introduced a bias towards underestimation. This could be due to us selecting tests with the best sample quality. Prior knowledge and experience seem to have little effect on this result, when comparing MSc cohort 2 and BSc cohort 1. Prior knowledge assumes that all knowledge is retained, so that MSc students have a deeper understanding, but this is not necessarily the case. It should also be noted that the MSc students were a rather heterogeneous group, compared to the BSc students who all had identical geotechnical background. Hence, misconceptions students have developed on fundamental mechanisms in other courses might have influenced the results (Clements 1982; Pantazidou 2009).

A potential misconception lies in the understanding of the serviceability limit state (SLS) design (the prediction project), as opposed to the ultimate limit state (ULS) design the students are most familiar with. It is hypothesized that using conservative best estimate values for the undrained strength in ULS design (taught in prior courses) is leading to underestimation of the compressibility. A low value of C_c leads to lower predicted settlements, which is counterintuitive for students used to deal with Young's moduli in other courses. The same applies for the coefficient of consolidation: the students underestimated rate of consolidation, often by choosing c_v values corresponding to the normally consolidated range, and hence the predicted settlement-rate was underestimated.

Feedback is essential in teaching and engineering practice. Due to lack of understanding and context, the students (and engineers) respond poorly to feedback (Sadler 2010). The intention of the "Class C" prediction element in the project was to incorporate feedback in a non-judgemental manner. Asaoka's method (Asaoka 1978) enables identification of the possible source of the error by enabling the calculation of (a) the final amount of settlement as well as (b) the rate of settlement in the field (that also includes the effects of creep in the measurement data). Unfortunately, the students who predicted the outliers also struggled with Asaoka's method and were hence rather clueless. In contrast, due to the limitations of Asaoka's method for our data (i.e. presence of significant creep) the students with a good initial prediction had no obvious source of errors. This is perhaps something that could be overcome by peer review.

Finally, all predicted time series have been compiled in Figure 9. Clearly, limiting the method to be used for the settlement calculations takes out some of the outliers in the over-prediction side. Encouragingly, the scatter in the predictions by the MSc cohort 2 is very similar with those of the professionals, and the same applies to the majority of the BSc students.

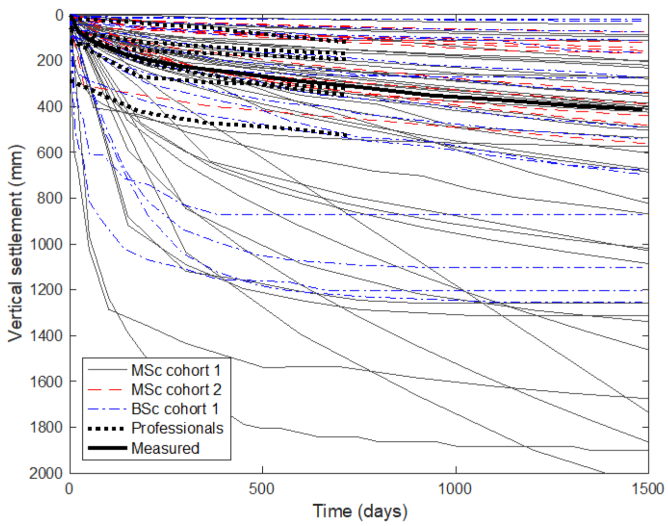

Figure 9. Measured time series for the vertical settlement directly below the embankment at the centre line and predictions by professionals and students

6 Conclusions

Geotechnical engineers have to deal with natural soils and the uncertainties associated with the formation history, design methods and available data from the laboratory and the field. Adding a "Class B & C" prediction project in the course is a suitable instrument to teach these notions, whilst engaging the students in active learning. The current paper demonstrates that creating a successful project is far from trivial. Depending on the degree of the alignment between the lectures, tutorials and the project work, the amount and quality of the data provided, prior conceptions and the quality of the feedback mechanisms, results may vary. When comparing all predictions together, it is comforting though that most students performed as well as the professionals.

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Invited author's bio

Minna Karstunen, Chalmers University of Technology, Sweden

Minna Karstunen is Professor in Geotechnical Engineering at Chalmers University of Technology, Sweden and a Fellow of the Institution of Civil Engineers, UK. She got her PhD at University of Wales Swansea in 1998, followed by a successful academic career in the UK. She joined Chalmers in 2012, where she has built an internationally leading research group focussing on modelling soil and rocks across the scales. Minna's industrial experience relates to the design of roads, tunnels and bridge foundations on very soft soils in Finland and she is involved as an independent expert in the West Link project in Sweden. Minna is internationally known for her research on constitutive model development, aimed at representing the complex rate-dependent stress-strain behaviour of sensitive soft clays. She has coordinated a number of European projects related to soft soil modelling and soft clay engineering and has published over 100 scientific publications. Minna has taught Geotechnical Engineering at undergraduate and post-graduate level at six universities in four countries, with three languages. In addition, she has organised/contributed to numerous PhD courses and training events, as well as given courses for industry related to numerical modelling of soils.

Forks in the Road: Rethinking Modeling Decisions that Defined the Teaching and Practice of Geotechnical Engineering

R. Salgado

Purdue University, West Lafayette, IN, USA
rodrigo@ecn.purdue.edu

ABSTRACT: Geotechnical engineering is a discipline that evolved in response to the need to design structures on, in or of soil and rock. It spans a wide range of applications, including tunnels, foundations, dams, and retaining structures. It deals with a material known to be difficult to model: a particulate material whose mechanical response is affected by all three invariants of the stress tensor, by density and by fabric. This paper and the corresponding lecture focus on mechanics-based geotechnical engineering applications. The paper reviews some of the major decisions that were made by the engineers and researchers who developed geotechnical engineering to the point at which it was an identifiable separate discipline and the consequences that these decisions have had on the development of the discipline and on its teaching. The paper identifies some key modeling choices that were made that have had a disproportionate impact on the teaching and practice of geotechnical engineering. The focus of the paper is therefore on these decisions and choices, and what should be taught in their place today.

Keywords: geotechnical engineering, education, sand, clay, Mohr-Coulomb yield criterion, Tresca yield criterion, dilatancy

1 Empiricism, Science and Geotechnical Design

1.1 The Pre-Science Days

Construction in, on or with soil is nothing new: we have been building structures of the most varied types for millennia. One might infer from that that geotechnical engineering, which is the engineering of structures or systems of which soil is an integral part, would be a settled subject. In some ways it is, for geotechnical structures do get built; and these structures are typically designed with methods developed over the course of the last several decades. However, the fact that we can design and construct does not mean that we do these things as well as we could, and it does not mean that the models that we use in analysis and design are correct.

In any type of activity, improved processes and products result from trial and error, but only up to a point. This attempt to arrive at better ways of doing things without a full understanding of the factors at play and their interrelationships is known to us as empiricism, and progress can at times be painful. An interesting twist in how both individuals and populations learn and add to knowledge in an empirical manner resulted from the development of the World Wide Web, the internet and smart search engines. The combination of these three technologies, and the access by a large fraction of the Earth's population to them has given people much more access to knowledge and the possibility of experimenting with knowledge they find online, keeping what works, and discarding what does not. Whereas individuals in their daily lives and people working in the trades have benefited from the rapidly accumulating body of easily accessible specialized knowledge, it is possible to argue that the same is not true of a profession, which geotechnical engineering is. The reason for this is that, at least for the more challenging projects, the engineering profession today must rely on science, and science cannot be found or taught or developed so easily and so loosely. Not to rely on science would take us back a hundred years, when results in terms of economy and safety were far from satisfactory.

There is a common misconception that all engineering done before the advent of science was conservatively done. The inference seems to be common-sensical, because it would be natural to proceed cautiously when one does not know very well what one is doing, i.e., when one is proceeding by trial and error. However, that has not necessarily been so. While cases of serious engineering failures would not have appeared in geotechnical scientific journals – because they did not exist before the second half of the 20th century – we can still learn about how things could go wrong in the pre-science days of geotechnical engineering by referring, for example, to court decisions. An interesting case is that of *Stees v. Leonard*. Here is an excerpt of a pertinent part:

> The action was brought to recover damages for a failure of defendants to erect and complete a building on a lot of plaintiffs, on Minnesota street, between Third and Fourth streets, in the city of St. Paul, which, by an agreement under seal between them and plaintiffs, the defendants had agreed to build, erect, and complete, according to plans and specifications annexed to and made part of the agreement. The defendants *commenced the construction of the building, and had carried it to the height of three stories, when it fell to the ground. The next year, 1869, they began again and carried it to the same height as before, when it again fell to the ground,* whereupon defendants refused to perform the contract.
>
> *Stees v. Leonard,* 20 Minn. 494, 449 (1874). (emphasis added)

There are other cases like this recorded in court proceedings that show the inadequacy of a trial-and-error approach, which lacks a basis on the underlying science. The number of events is most certainly a multiple of those we can learn about from consulting such records. Starting a geotechnical engineering course with a case history like this, and following that with a discussion of the scientific method gives students an appreciation for what the subject is about, its importance, and why science matters.

1.2 The Development of the Science

The scientific method is the formulation of a hypothesis about some question or problem and then the idealization and execution of experiments to validate the hypothesis. If the hypothesis is properly validated, we have a model, which we can then use to guide further scientific inquiry or the development of engineering design methods. Until the early 20th century, all that anyone working with soil and rock could count on was empirical knowledge. It was not until scientists like Forcheimer (whom his student, Karl Terzaghi, later emulated in many respects) started seeking to frame some flow problems as boundary-value problems (Goodman, 1999) that the science of soil mechanics started coming into form. It was a natural step to go from flow problems to consolidation theory, and that development is credited as the birth of soil mechanics. Although Terzaghi's one-dimensional consolidation theory was imperfect – see, e.g., Goodman (1999) and Salgado (2008) for an account of why that is so and of the sad events involving Terzaghi and Forcheimer – its flaws were not fatal to its application to a range of practical problems, and it was by no means a misstep. It will not be discussed further in the present paper.

Once consolidation theory was in place, the same general approach – looking for the science to underpin design methods in the incipient engineering discipline that we now call geotechnical engineering – was followed for other problems. Bearing capacity theory, as an example, follows from work done during the industrial revolution on metal indentation (Prandtl, 1920, 1921; Reissner, 1924). This path was by no means easy, and, faced with hurdles, the pioneers took detours and made decisions that have had significant implications on how geotechnical engineering is practiced and how it is taught at universities even today.

1.3 What Does this Paper Cover?

This paper examines how these difficulties and resulting decisions, many related to how to model the mechanical response of soil, have shaped the development of the discipline and its teaching. Understanding of soil mechanics is vastly superior today. I will propose some ideas regarding key content that should be taught at the undergraduate and graduate level that is consistent with current understanding and that – contrary to opinions sometimes verbalized – is easily learned by students. Due to space limitations, the paper covers only three of the fundamental model choices that shaped soil mechanics and geotechnical engineering, but there are more.

The three topics addressed are the use of the Mohr-Coulomb and Tresca yield criteria to model soil shear strength, the use of an associated flow rule with these models, and the neglect of shear strain localization. These choices have guided the development of the discipline and have led to a significant body of work. Among topics not covered are the reliance of analyses on infinitesimal strains, the neglect of fabric effects on material response, and the use of total-stress undrained analyses in clays.

The paper is very much focused on the content that should be taught, rather than teaching approaches and pedagogy. However, I will also discuss, albeit somewhat superficially, possible approaches to better teaching the right content.

2 The Original Sin: Soil as a Mohr-Coulomb Material and Clay as a "Cohesive" Material

2.1 Background

To understand why, today, students learn that there are two types of soils – "cohesionless soils" and "cohesive soils" – we must travel back to the 1950s, when the science of soil mechanics was in development. After a relatively successful study of 1D consolidation using the coupling of deformation with flow, Terzaghi and co-workers set about dealing with problems involving shear strength, such as the calculation of the bearing capacity of foundations.

The state of the mechanics of foundations at the time was fundamentally this: little progress had been made over the practice of foundation engineering in the preceding century. We discussed earlier the case of *Stees v. Leonard*, in which a contractor tried, not once, but twice, to erect a building on soil that could not support it. In the lawsuit that followed, they misidentified the cause of the problem, which was a bearing capacity problem, as the existence of a "quick sand" at the site. But, even as the understanding that one must design against bearing capacity "failures" – i.e., bearing capacity ultimate limit states – started forming, the means to calculate this bearing capacity lagged behind.

The practice of foundation engineering was to try and build based on prior experience, an experience that was often not applicable to the conditions at hand. In this environment, in which scientific knowledge hardly existed, it is not surprising that Terzaghi believed that "[b]ecause of the unavoidable uncertainties involved in the fundamental assumptions of the theories and in the numerical values of the soil constants, simplicity is of much greater importance than accuracy." (Terzaghi & Peck, 1967 at 153). This thinking permeated much of Terzaghi's work at the time, and it is therefore no surprise that he also believed that "[i]n spite of the apparent simplicity of their general characteristics, the mechanical properties of real sands and clays are so complex that a rigorous mathematical analysis of their behavior is impossible." (Terzaghi, 1943 at 5).

We now know that there are three things that are incorrect in Terzaghi's two statements. First, simplicity and accuracy are not to be directly compared. Something can be both simple and inaccurate, and *vice-versa*. To state that something simple but inaccurate is superior to something not simple but accurate does not appear sensible. Second, the mechanical properties of sand and clay are not even apparently simple. Refer to Figure 1 and Figure 2 for stress-strain plots for sand and clay sheared under drained and undrained conditions in triaxial compression. The stress q in the figures is the Mises shear stress (a multiple of the octahedral shear stress). Without an understanding of the mechanics of these soils, it is impossible to make sense of transitions and reversals between contractive and dilative response, of the existence of a peak shear stress to normal effective stress ratio, of the existence of a critical state, or of the transition to a residual strength at large shear strains and sufficiently large normal effective stresses for clays. Lastly, the final part of Terzaghi's second statement is also (today) incorrect, because researchers are developing fairly rigorous relationships for modeling soil behavior. Monotonic mechanical response is not considered today a challenge to model (see e.g., Chakraborty et al., 2013b; Dafalias & Herrmann, 1986; Li & Dafalias, 2000; Loukidis & Salgado, 2009b; Manzari & Dafalias, 1997; Woo & Salgado, 2015). Figure 1 and Figure 2 show simulations done using an advanced constitutive model that clearly match the experimental response quite well.

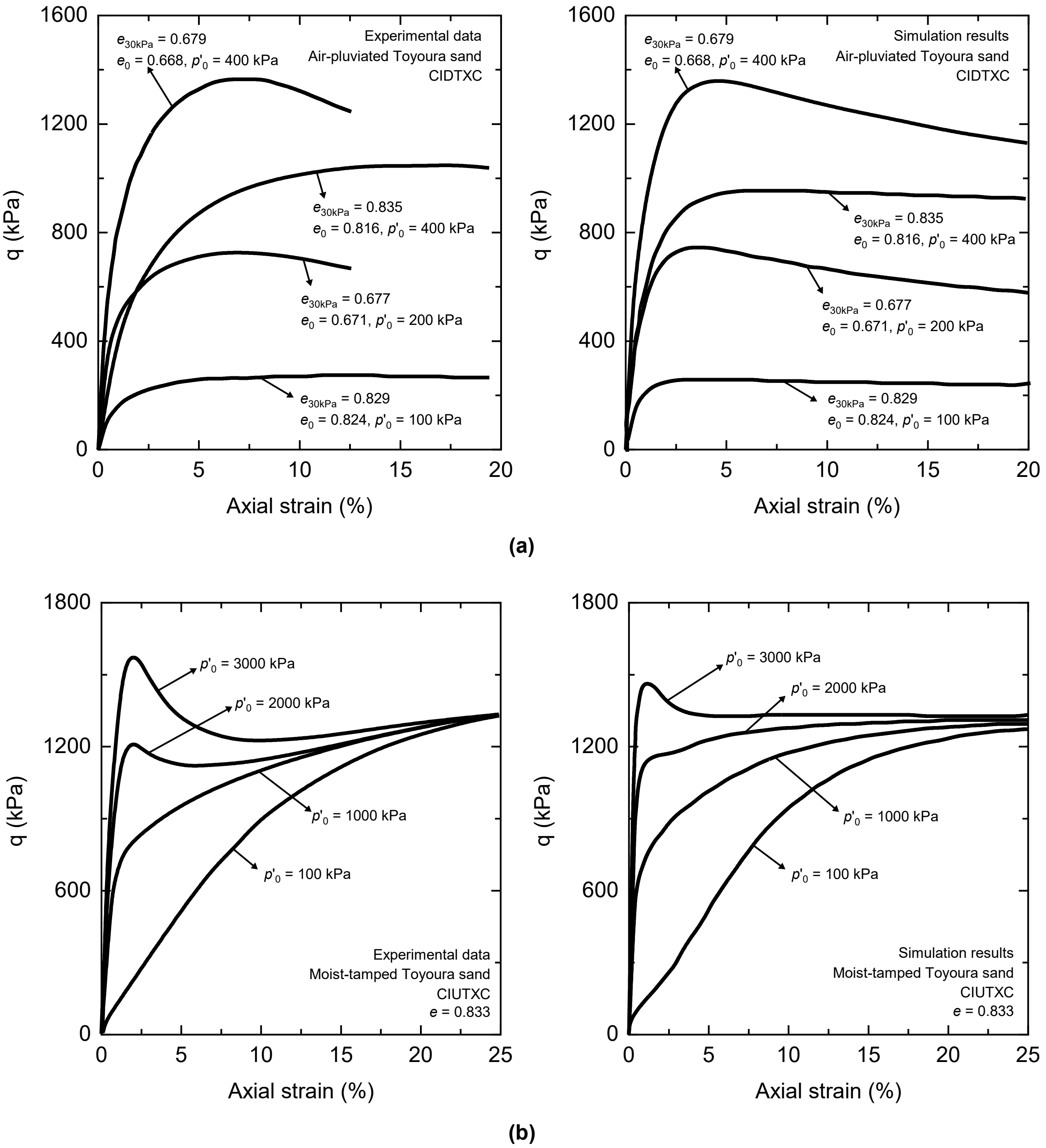


Figure 1. Results of triaxial compression test results performed on sands: (a) drained (b) undrained (Woo & Salgado, 2015)

Faced with what he deemed an impossibility, it is not surprising that Terzaghi proposed the concepts of an "ideal sand" – a linear elastic, perfectly plastic Mohr-Coulomb type of material with non-zero friction angle and c = 0 – and an "ideal clay" – a linear elastic, perfectly plastic material following a Tresca yield criterion (Terzaghi, 1943). Terzaghi referred to this material as a "cohesive" material, a term that survives to this day. As to sand, engineers soon started assuming non-zero cohesion also for sand, deviating from the original "ideal sand" concept that Terzaghi had advanced.

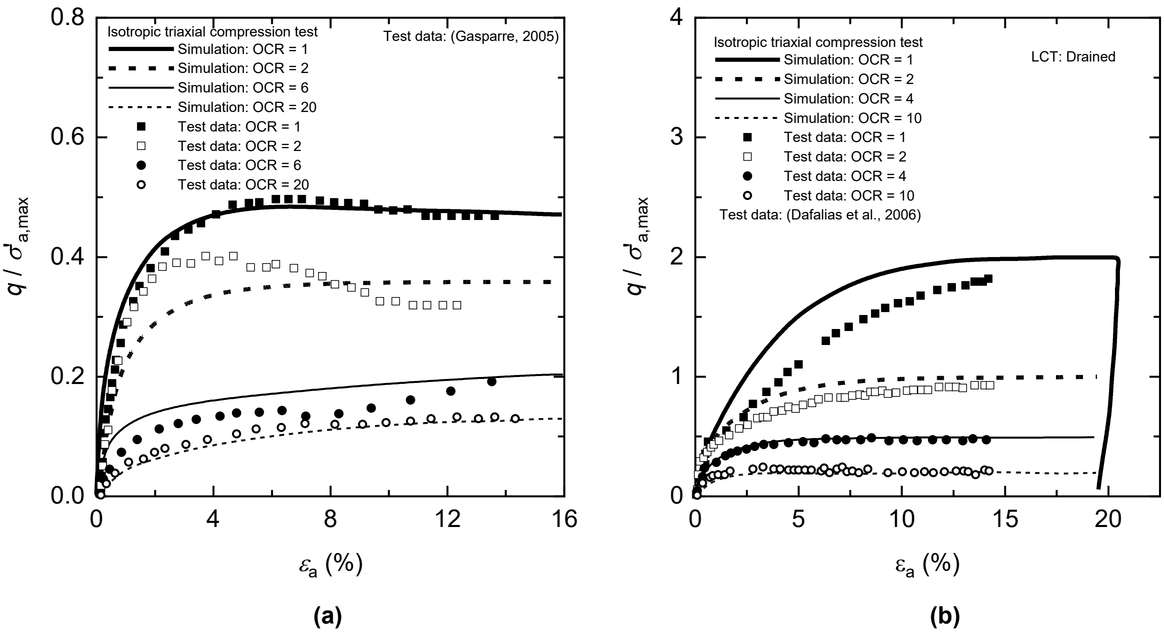


Figure 2. Results of triaxial compression tests performed on clays: (a) undrained (b) drained (Chakraborty et al. 2013b; Dafalias et al., 2006; Gasparre, 2005)

So a Mohr-Coulomb yield criterion (Figure 3a) would be used for sand, and a Tresca yield criterion (Figure 3b) would be used for clay. The only way to understand this postulation is to assume that Terzaghi observed increasing strengths for sand tested at increasing confining stresses under drained conditions, but constant strength for clay with increasing *total stresses* when samples were tested under undrained conditions. Based on this limited set of observations, Terzaghi postulated behaviors for soil that are not real. To this, Schofield (1988) later referred as "Terzaghi's error." This criticism is tempered by the recognition that the "ideal clay" model turned out to be an effective basis to build a body of analysis for problems involving saturated clay and that even erroneous models of soil behavior were better than the crude form of knowledge available in those days. Additionally, the greater harm concerning sands was the subsequent use of a Mohr-Coulomb material with nonzero cohesion for sand, rather than the original ideal sand concept. Consequently, some viable theories have evolved from these simple "ideal" soil models, but the failure to accurately describe the sources of shear strength in soils remained.

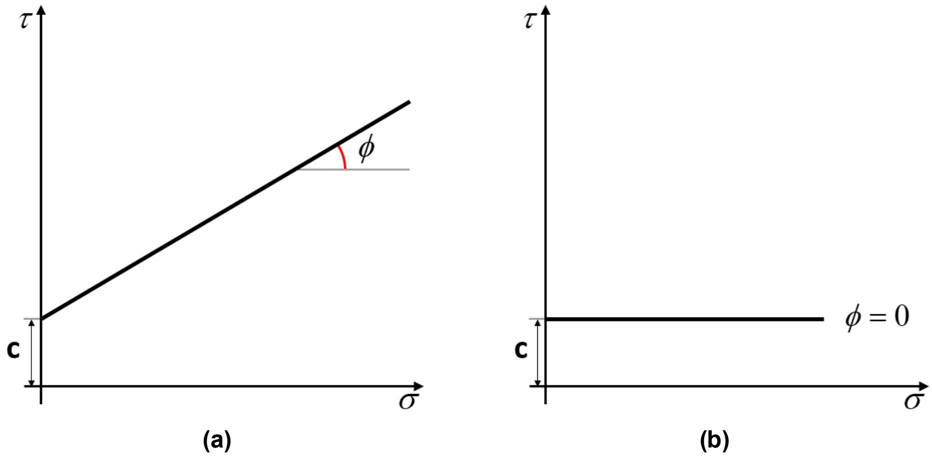


Figure 3. Relationship between normal and shear stresses for (a) a Mohr-Coulomb material, idealized in the 1950s as an "ideal sand" if c= 0 and (b) a Tresca material, idealized in the 1950s as an "ideal clay"

2.2 The Error

We have argued that Terzaghi's "ideal sand" and "ideal clay" models led to an erroneous description of soil behaviour. This is true even if one is simply interested in calculating shear strengths and has no interest in realistically simulating any other aspects of behaviour. But why is it so? For the answer, we look to plasticity theory.

Perhaps nothing has been as damaging to the teaching of soil mechanics than the notion that soil can generally be considered to follow the Mohr-Coulomb yield criterion. A material that follows the Mohr-Coulomb yield criterion experiences plastic strains only when the stress state satisfies the relationship:

$$F = (\sigma_1 - \sigma_3) - (\sigma_1 + \sigma_3)\sin\phi - 2c\cos\phi = 0 \tag{1}$$

where σ_1 and σ_3 are the maximum and minimum principal stresses, respectively. The function F of stresses is referred to as the yield function, and $F = 0$ is referred to as the yield criterion. The parameters ϕ and c are the friction angle and the cohesion, respectively, of the material. Terzaghi's ideal sand has non-zero ϕ and $c = 0$, and the ideal clay has zero ϕ. In later work, engineers abandoned the original concept of zero c in sand and started using nonzero c and ϕ to describe sand. No explanation was provided for the source of what should amount to a frictional strength component and a stress-independent (frictionless or cohesive) strength component. What this step left both educators and practitioners with was a model that was not based on an understanding of soil behaviour, since ϕ and c were the starting point of the analysis: the model fundamental parameters.

Unfortunate implications of this paradigm were the misunderstanding that clean, uncemented sands could have non-zero *c*, and that clays had a constant *c*, a result directly implied by the "ideal clay" model. Initially, educators taught students that a set of tests had to be done at more or less the "appropriate" level of effective stresses, and straight-line fits to the corresponding data points would yield the correct values of ϕ and *c*. This presented a variety of questions, one of which regarded the applicable level of effective stress for a problem in which the soil experiences a wide range of stress levels, as in the bearing capacity problem. In some of these problems, stresses can be as high as several or even tens of megapascals. Clearly, performing shear strength tests at these elevated stress levels was not realistic.

Fortunately, even as Terzaghi made these influential choices, others (e.g., Taylor, 1948) were attempting to understand what the real sources of shear strength were. Taylor laid the foundation for what would later be known as critical-state soil mechanics. In this framework for the mechanics of soil, soil is a frictional material capable of volume change; a second source of shear strength results from this dilative response.

2.3 What Should Be Taught Instead

What emanated from the studies of Roscoe et al. (1958), Schofield (2006), Taylor (1948) and others was the understanding that soil is always a frictional material. In the absence of cementation, a fully saturated or completely dry soil derives its strength exclusively from friction if under sufficiently high confining stress and/or sufficiently low density (see, e.g., Salgado, 2008). If either density is sufficiently high or stress is sufficiently low, soil also derives its strength from dilatancy.

It follows that, whether teaching at the graduate or undergraduate level, we should teach our students that soil takes its strength from two sources: friction and dilatancy. It is essential to stress that unstructured soil (soil without cementation or any source of extraneous cohesion) is frictional, lacking cohesion. A good starting point for this discussion is plastic deformation in the absence of any tendency to change volume: the so-called critical state. Surprisingly, based on anecdotal evidence, this is a concept that undergraduate students are often not exposed to. The concept is however easy to teach. The easiest way to teach it is to show students that the critical state is simply a purely frictional state. At critical state, the soil derives its strength from the frictional strength between soil particles, there being no other source of shear strength. And frictional strength only exists in the presence of non-zero effective normal stress.

It is sometimes surprising to students who have somehow learned otherwise that even clays are purely frictional materials. An example that can be used to get this last point across is that of a clay deposit forming at the bottom of a lake (Salgado, 2008). It is easy for students to understand that the soil right at the surface of the bottom of the lake, composed of particles that have recently deposited out of water, lacks shear strength. The reason for that is that the clay there is almost a slurry: it is under zero effective stress and has very high void ratio. In the absence of a normal effective stress, that clay has zero shear strength because it is a frictional material. An example for sand that can be given, to which undergraduate students can easily relate, is that someone picking up some sand on the beach can easily manipulate the soil, for it lacks strength, and it lacks strength because it is under nearly zero normal effective stress.

The other component of shear strength is due to dilatancy, which can best be explained by referring to a figure such as Figure 4, which shows that spherical particles that are closely packed must separate in the direction normal to that of shearing. This separation must occur against an existing normal effective stress, which requires work to be done. Where does the work come from? From the applied shear stress. So the applied shear stress must overcome not only frictional strength to cause the material to deform plastically, but also this confining stress opposing the required soil dilation.

These two concepts are easy for students to understand. This basic understanding of the physical processes underlying shear strength development in soil can then be used throughout their course of study of geotechnical engineering applications (retaining structures, foundations, slopes and other structures), and should effectively inoculate them against the flawed concepts of "cohesive" or "cohesive-frictional" soils. From that point on, students will understand that soils are truly potentially dilative, frictional materials.

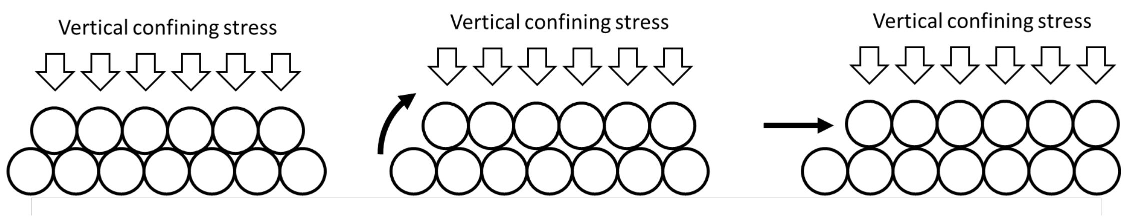


Figure 4. Particle climbing action for densely arranged particles (Salgado, 2008)

At the undergraduate level, one of the easiest ways to teach how dilatancy works is to use the Bolton (1986) framework for sands. This work has been extensively referred to and has been extended to apply to sands with fines (see, e.g., Carraro et al., 2009; Salgado et al., 2000) and sands at low confining stresses (Chakraborty & Salgado, 2010). Concisely, for a sand, the peak friction angle ϕ_p is written as the summation of a critical-state friction angle ϕ_c plus an angle due to dilatancy:

$$\phi_p = \phi_c + A_\psi I_R \tag{2}$$

where A_Ψ is a parameter in Bolton's equation having value of 3 for triaxial conditions and 5 for plain-strain conditions, and I_R is the relative dilatancy index given by:

$$I_R = I_D(Q - \ln p') - R \tag{3}$$

where I_D is relative density, p' is the mean effective stress and *Q and R* are fitting parameters.

At the Ph.D. level, one must go much beyond this. It is important then to cover constitutive modeling (mainly the most recent models, such as bounding-surface models) and particle-based methods.

3 Building on the Original Sin: Reliance on the Associated Flow Rule

3.1 Background

The teaching of geotechnical engineering tends to emphasize stresses, but strains are just as much a part of the solution to any boundary-value problems in geomechanics. The only exposure that students seem to get to strains is that stress-strain plots are typically shown or obtained in the laboratory and during the coverage of consolidation. A standard discussion surrounds the facts that loose sands contract or dilate less than dense sands and that dense sands may contract initially, but then end up being ultimately dilative. Strains are typically not linked back to stresses with any rigor, and that is sometimes true even at the graduate level. Yet, this link is crucial to the modeling of the mechanical response of soil.

The relationship is rather obvious to students in the context of elasticity. There is a general sense that application of a stress increment leads to a strain increment, and that its removal returns the body to its original configuration. When it comes to plasticity, matters turn more complex.

The rate of the plastic strain tensor in classical plasticity models is obtained from the plastic flow rule:

$$\dot{\varepsilon}_{ij}^{p} = \dot{\lambda}\frac{\partial G}{\partial \sigma_{ij}} \tag{4}$$

where i and j are indices taking values 1, 2 or 3; σ_{ij} are the six components of the (symmetric) stress tensor; $\dot{\lambda}$ is the plastic multiplier; and G is the plastic potential, a function of the stress tensor:

$$G = G(\sigma) \tag{5}$$

Given that there are six independent stress components, Equation (4) states that the plastic strain increments, or rates are determined by a six-dimensional surface defined by Equation (5). The meaning of the term $\partial G/\partial \sigma_{ij}$ is that of a gradient in that space. This can best be visualized if we represent the stress tensor using its three principal stresses, in which case we are able to represent these equations in 3-dimensional space (see Figure 5). The gradient can then be visualized as being normal to the 3-dimensional surface defined by Equation (5). This visualization of a 6-dimensional process in 3-dimensional space can only be taken so far, as discussed by Woo & Salgado (2014).

If the gradient is aligned with the σ_1 axis, for example, that means that only the ε_1 strain component will change, with $\dot{\varepsilon}_2 = \dot{\varepsilon}_3 = 0$. So $\partial G/\partial \sigma_{ij}$ determines the proportion or ratio between each pair of strain rate components.

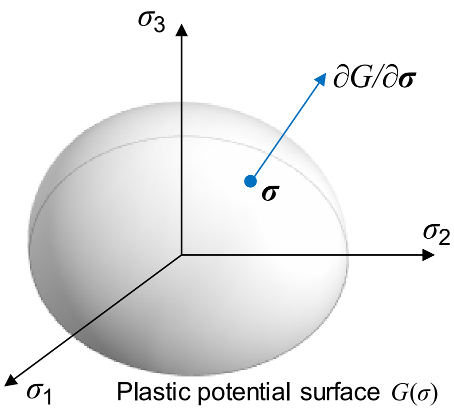


Figure 5. Plastic potential surface represented in principal stress space and its stress gradient, which enters the formualtions of the flow rule

In metal plasticity, which developed considerably during the industrial revolution, it was observed that there was no plastic volume change during plastic deformation. Although we don't show this here, this leads to the result that plastic strain rate is normal to the yield surface given by Equation (1) if plastic strains are plotted in the same space (with a separate scale) as stresses. This led to the adoption of what we now call an associated flow rule for the plastic strain rate, where F is used as the plastic potential:

$$\dot{\varepsilon}_{ij}^{p} = \dot{\lambda}\frac{\partial F}{\partial \sigma_{ij}} \tag{6}$$

If we are working with clays using total stresses in undrained loading simulations, we are in effect using Terzaghi's "ideal clay" model. There is then no volumetric strain, and Equation (6) is approximately applicable. In drained simulations or effective-stress simulations, an associated flow rule does not apply. This can be observed by performing experiments and observing the lack of normality between the plastic strain rate and the yield surface. However, it is important to understand what the fundamental error of use of an associated flow rule is in those cases.

3.2 The Error

A material undergoing plastic deformation (yielding), in contrast with only elastic deformation, dissipates energy. We can think of energy dissipation as the energy that has to be expended to change the material internally (i.e., to permanently deform it in some manner). The rate of plastic energy dissipation D_p per unit volume for infinitesimal-strain plasticity is given by:

$$D_p = \sigma_{ij}\dot{\varepsilon}_{ij}^{p} \tag{7}$$

where σ_{ij} is the stress, and $\dot{\varepsilon}_{ij}^{p}$ is the time rate of plastic strain.

Taking Equation (1) and Equation (6) into Equation (7), we obtain the following for the rate of plastic dissipation:

$$D_p = \dot{\lambda}[2c\cos\phi] \tag{8}$$

What Equation (8) tells us is that the rate of plastic energy dissipation is entirely due to the existence of a cohesion c. If $c = 0$, then no energy is dissipated during plastic flow. If we think of a sand in realistic terms, it has no cohesion. So Equation (8) is telling us that sand does not dissipate energy, which we know to be incorrect. This result is also baffling for the typical graduate student. How can a cohesive-frictional material, for that is what a Mohr-Coulomb material is supposed to be, dissipate no energy upon plastic deformation when $c = 0$? Is friction not intricately linked to energy dissipation?

The inescapable conclusion is that the use of the Mohr-Coulomb yield criterion with an associated flow rule to model real soils in effective-stress analysis is simply wrong. A sand loaded under drained conditions, which corresponds to the vast majority of applications involving sands, and is correspondingly taught quite often, cannot be modeled with a Mohr-Coulomb model even as an approximation, unless a flow rule that is not associated is used. Unfortunately, drained analysis with a Mohr-Coulomb material and an associated flow rule is what a large body of work in geotechnical engineering is based on. This is the content that many, if not most, geotechnical engineering students get in the classroom.

3.3 What Must Be Taught Instead

If one must use the Mohr-Coulomb model, it is important not to teach any of the theories in which an associated flow rule was assumed and, where needed, stress that the flow rule for a Mohr-Coulomb material cannot be associated if realism is to be achieved. This difference is far from just conceptual, with important numerical consequences.

Consider, for example, the bearing capacity problem in sand. The unit bearing capacity q_{bL} in sand can be seen as the summation of two terms:

$$q_{bL} = q_0 N_q + \frac{1}{2}\gamma B N_\gamma \tag{9}$$

where q_0 = overburden stress, γ = unit weight, and N_q and N_γ are bearing capacity factors. We ignore any depth correction factor that might be incorporated into Equation (9) for the purposes of the discussion that follows. The classical equations for the two bearing capacity factors are:

$$N_\gamma = 1.5\left(N_q - 1\right)\tan\phi \tag{10}$$

and

$$N_q = \frac{1+\sin\phi}{1-\sin\phi}e^{\pi\tan\phi} \tag{11}$$

Equation (10) is due to Brinch Hansen (1970), who proposed it based on results from the method of characteristics. The method of characteristics assumes an associated flow rule, as does most of the work published using limit analysis. We now know that these two equations cannot be correct, for sand does not follow an associated flow rule. How wrong are the results? We can answer this by referring to the equations proposed by Loukidis & Salgado (2009a) for a sand with a non-associated flow rule:

$$N_q = \frac{1+\sin\phi}{1-\sin\phi} e^{J(\phi,\psi)\pi\tan\phi} \tag{12}$$

and

$$N_\gamma = \left(N_q - 1\right)\tan(1.34\phi) \tag{13}$$

where J is a function given by

$$J(\phi,\psi) = 1 - \tan\phi\left[\tan(0.8(\phi-\psi))\right]^{2.5} \tag{14}$$

and ψ is the dilatancy angle.

The dilatancy angle is defined as:

$$\sin\psi = -\frac{\dot{\varepsilon}_v}{\dot{\gamma}_{max}} \tag{15}$$

where $\dot{\varepsilon}_v$ is the time rate of volumetric strain and $\dot{\gamma}_{max}$ is the rate of the maximum shear strain.

The dilatancy angle is a measure of how much volumetric strain results from shearing of the material. A flow rule associated with the Mohr-Coulomb yield function leads to $\psi = \phi$. It is more realistic for sands to assume $\psi < \phi$. This would correspond to a non-associated flow rule. Figure 6 illustrates the impact that the choice of an associated instead of a non-associated flow rule has on engineering computations related to the bearing capacity problem. The figure shows value of N_γ resulting from realistic pairings of ψ and ϕ and from $\psi = \phi$. Values for $\psi = \phi$ significantly exceed value for $\psi < \phi$.

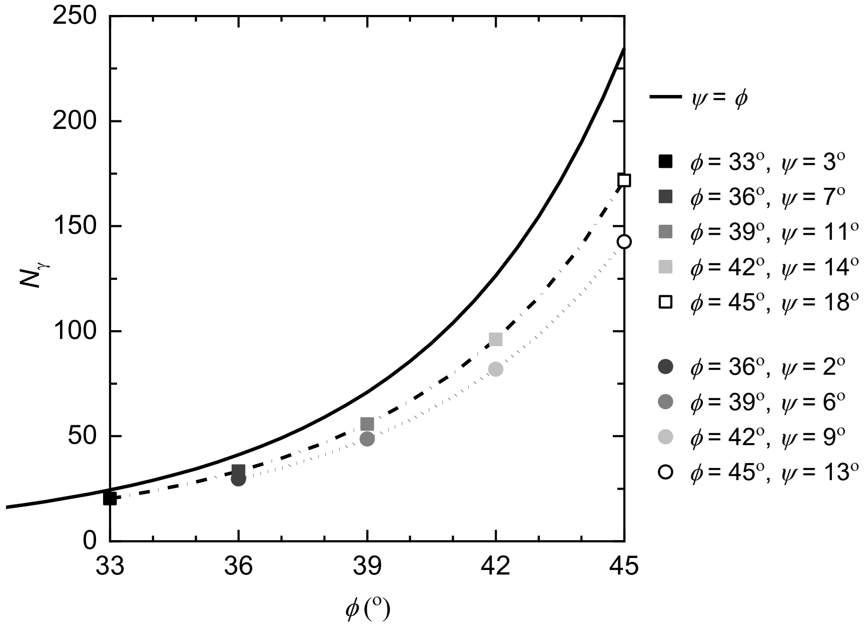


Figure 6. Comparison of values of bearing capacity factor N_γ calculated based on the assumption of associated flow ($\psi = \phi$) with values calculated based on non-associated flow ($\psi < \phi$)

How much difference does the choice of flow rule make in the calculation of the bearing capacity of a footing? Let us consider the bearing capacity factors and the limit bearing capacity q_{bL} of strip footings calculated using the two sets of equations. As an example, we take a friction angle ϕ = 45°; dilatancy angle ψ = 45° and 18°; and unit weight of sand = 19 kN/m^3. Table 1 presents the computed bearing capacity factors – N_γ and N_q – and the bearing capacity q_{bL} of two strip footings with width B = 1 m and 2 m, with an embedment of 0 m and 1 m, with the depth factor on the overburden term of the bearing capacity equation neglected.

Table 1. Effect of flow rule non-associativity on bearing capacity of strip footings: results of calculations using Equations (12) and (13)

Flow rule	ϕ (°)	ψ (°)	N_q	N_γ	q_{bL} (kN/m^2)			
					embedment = 0 m		embedment = 1 m	
					B = 1 m	B = 2 m	B = 1 m	B = 2 m
Associated	45	45	135	235	2230	4459	4792	7022
Non-associated		18	99	172	1631	3262	3511	5142

The resulting bearing capacity for footing on the surface of a deposit of the material following the associated flow rule is 37% greater than that calculated for a material following the non-associated flow rule. This very significant overestimation of the bearing capacity of a strip footing resulting from use of the associated flow rule is an error that is unconservative. Given the nature of shallow foundation design, with serviceability controlling in the vast majority of design cases, this error does not have the detrimental impact that it otherwise would.

This simple example, for one of the classical problems of soil mechanics, illustrates the level of error resulting from use of theories based on a Mohr-Coulomb material following an associated flow rule. Ideally, these would not be taught but for providing historical perspective. The teaching of methods of analysis and design that rely on realistic soil models would be the best approach, and it is possible in many instances. Failing that, whenever the Mohr-Coulomb yield criterion is used, it must be used with a non-associated flow rule.

Lastly, use of a non-associated flow rule does not heal the defects of a model relying on the Mohr-Coulomb yield criterion. The model is still exceedingly simple – having constant ϕ and ψ – and will not be realistic for calculations requiring a higher degree of realism. In such cases, use of a more sophisticated constitutive model is required.

4 Shear Strain Localization and its Implications

4.1 Background

In undergraduate laboratory classes, students typically see or perform triaxial tests on dense sand specimens; they observe the resulting "failure plane" that eventually develops through the specimen. In most classrooms, that observation leads to nothing more, but it should. That is the best time to make a number of crucial points that are today essential for a well-rounded geotechnical engineer to understand.

The first important point regarding that "failure plane" is that it is not a plane at all. The second is that "failure" is too vague a term, and it confuses students to use it. It is better to speak of what has happened as the shearing of the sand or, if one is especially attached to the word, as a shear "failure" of the sand specimen. Back to the first point, today it is possible to show students videos taken of the shearing of sand. In these videos, we can clearly see that a band of particles, with thickness of the order of 5 to as many as 20 particle diameters, is what constitutes that "plane." The "plane" is what we know today as a shear band.

Shear bands in soil have been studied as early as the 1970s (Vardoulakis et al., 1978). It is however very important to teach students this for the following reason: a plane is an abstraction from which no pattern of soil behaviour can be inferred, but a band, containing a number of soil particles, has a behaviour that results from the interactions of the particles in it. This interaction of particles in the band directly produces the constitutive behaviour of the soil. Once students understand this, it is much easier for them to understand how shaft resistance develops along a pile or why the pressure on a retaining wall is what it is.

The localization of shearing in a band results from the mechanical behaviour of soil: from the softening, i.e., loss of shear strength that occurs with the progression of shearing. With continuing shearing, the soil will tend to weaken at the location where this process first starts, shear strain then localizes there, sparing regions surrounding the band of further deformation. It is vital to understand this process because any simulations that we attempt of boundary-value problems involving such materials depends on correctly capturing the width of the shear bands. Mechanicians speak of the "length scale" of the material as determinative or intrinsically linked to the material behavior.

Shear bands are also seen in a Mohr-Coulomb soil following a non-associated flow rule. This is closely linked to the fact that, in these materials, plastic energy does dissipate – due to friction – once plastic shearing starts. It is then natural for shearing to continue where it started instead of diffusing to surrounding regions because that would require greater energy expenditure because of the plastic energy dissipation requirement.

Shear band thickness depends on essentially two things: (a) soil particle size and (b) whether it forms entirely within the soil or at an interface with a structural element. If the interface is rough, the shear band thickness will be of the order of the thickness that forms entirely within soil; however, if the interface is smooth, there is no shear band that forms along the interface: there is only clean sliding of the interface with respect to the soil (Tehrani et al., 2016; Tovar-Valencia et al., 2018). Images of strain localization can be collected through an exposed (transparent) window that allows visualization of soil during loading or, for small specimens, through X-Ray CT (e.g., Desrues et al., 2018). In approximate terms, shear bands in sand are of the order of 5 times the mean particle size for rough interfaces (Tehrani et al., 2016; Tovar-Valencia et al., 2018) to the order of 10 times the mean particle size for shear bands entirely contained in soil (Alshibli & Sture, 1999).

The simplest examples of localization and its impact on the solution of a boundary-value problem can be seen in the context of axially loaded piles, for which localization is known *a priori* to occur along the pile shaft (Han et al., 2017, 2018; Loukidis & Salgado, 2008; Salgado et al., 2017). Figure 7 shows the results of finite element analyses of an axially loaded pile in sand modelled using an advanced constitutive model in terms of the ratio K of the lateral effective stress on the pile shaft to the initial (free-field) vertical effective stress during shearing (Loukidis & Salgado, 2009b). It is seen in the figure that the shaft resistance calculated for a pile depends on the width of the finite elements used immediately next to the pile. As the finite element simulation progresses, shear strain localizes next to the pile in that "column" of elements. Consequently, the shear stress along the pile shaft at any given level of pile settlement depends on the response of that band of soil and how it responds to shearing. Pre-knowledge of what the shear band thickness is in a soil allows the correct calculation of the shaft resistance of the pile. The alternative is more difficult: use of a constitutive model and computational method that inherently have the correct length scale so that the correct final shear band pattern and thickness will result.

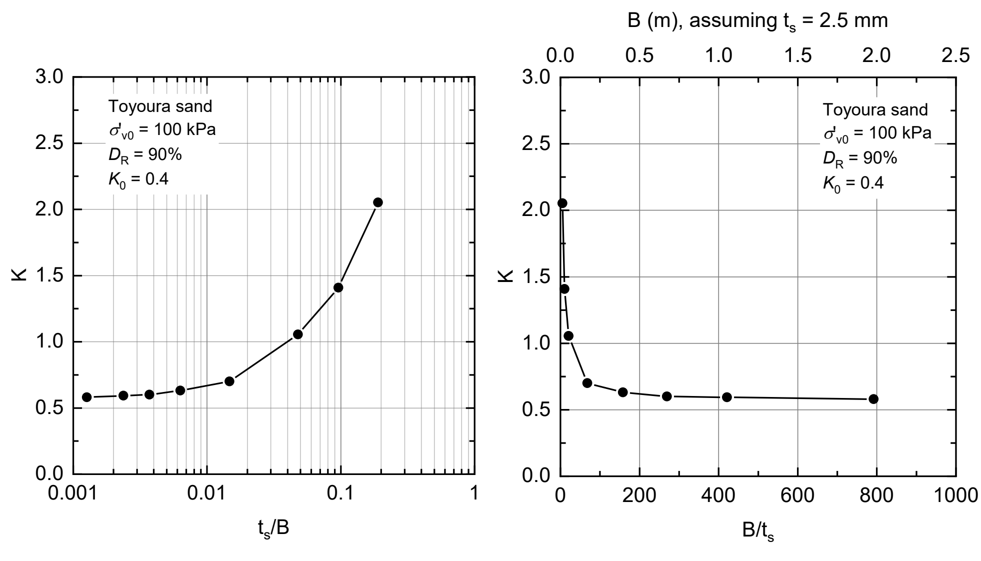


Figure 7. Effect of ratio of shear band thickness t_s to pile diameter B on shaft resistance (Salgado et al., 2017): (a) K vs. t_s/B and (b) K vs. B/t_s

4.2 The Shortcoming of Not Considering Shear Strain Localization

Students are often inundated with coverage of "elastic soil" or elasto-plastic soil following the Mohr-Coulomb or Tresca yield criteria. These are often observed in naïve use of commercial finite element software. An interesting illustration of how analyses using either an elastic soil model or an elasto-plastic soil model without realistic strength representation, strain softening and strain localization fall short comes again from foundation engineering.

Traditional models of pile group interaction relied on soil as an elastic material that transferred stresses between piles in a pile group (Poulos, 1968; Randolph & Wroth, 1979). This led to pile interaction and group efficiency coefficients that are unrealistic because the models did not account for strain localization, which significantly reduces interaction between neighbouring piles (Han et al., 2019). Figure 8 shows the significant difference in pile interaction within a group and group efficiency resulting from finite element analyses assuming a linear elastic soil, an elasto-plastic soil with a Mohr-Coulomb yield criterion, and a realistic sand model with an appropriately fine finite element mesh. These results show clearly that shear strain localization cannot be ignored if we desire accurate, realistic solutions to geotechnical boundary-value problems.

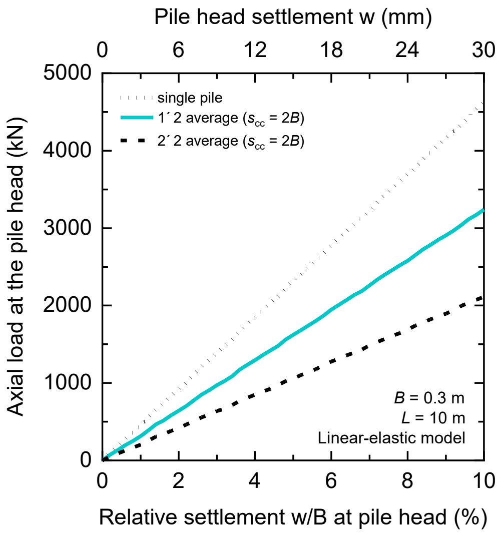
As a final illustration of the importance of capturing shear strain localization correctly, consider again the bearing capacity problem discussed earlier. Assume that a student or engineer decides to use a modern method of analysis or a commercial computational package to perform calculations for the same problem we discussed earlier. Table 2 shows results for calculations using SNAC (Abbo & Sloan, 2000), OptumG2 (Krabbenhoft et al., 2015) and the material point method (MPM) (Bisht & Salgado, 2018; Woo & Salgado, 2018). The values shown in the table are in reasonable agreement because consistent size for the mesh elements were chosen in these calculations. The SNAC and OptumG2 analyses were done using 15-node triangles with 12-point Gauss quadrature. The MPM analyses were done using Q4 elements with an initial number of material points per element equal to 4 and a B-bar scheme. The MPM analysis with the smallest element size e = 0.025m has approximately the same Gauss point density as the SNAC analysis, and the match between the two is evident. However, use of a coarser mesh, whether in SNAC, OPTUM or MPM would produce higher values of bearing capacity. For example, in the table, MPM with the smallest element size e = 0.1m yields a bearing capacity of 3055 kPa instead of 2241 kPa. This results from the fact that strain localization can only take place to the degree that the mass is discretized. A coarse mesh will lead to thick shear bands and a stiffer response.

Table 2. Strip footing bearing capacity computed using different numerical schemes and element sizes e

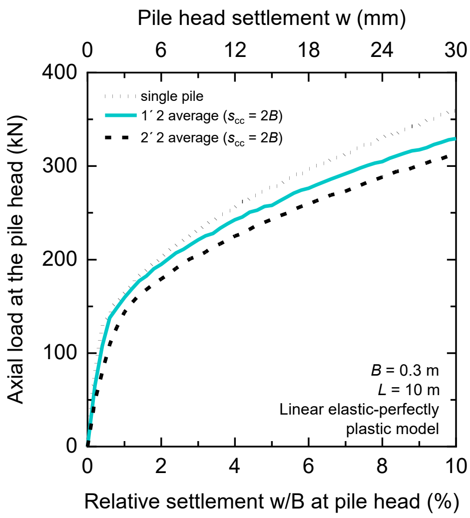
Flow rule	ϕ (°)	ψ (°)	q_{bL} (kN/m^2) (embedment = 0 m, B = 1 m)				
			SNAC	OptumG2	MPM		
					e = 0.1 m	e = 0.05 m	e = 0.025 m
Associated	45	45	2230	2307	3055	2301	2241
Non-associated	45	18	1631	1646	1924	1650	1611

4.3 What Should Be Taught Instead

Students should be acquainted with realistic stress-strain relationships under various loading paths, both drained and undrained, and should be provided with the opportunity to understand the role density, initial effective stress, dilatancy, and fabric evolution have in shaping these relationships. When exposed to problems in which shear strain localization occurs, and therefore the stress-strain history before localization is determinative of soil response, it is important to explain this and provide students with solutions and design methods based on analyses that do take localization into consideration.



(a)



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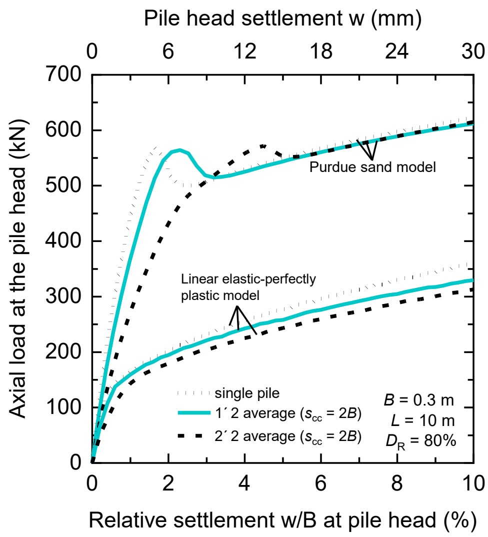

(c)

Figure 8. Load-settlement curves obtained from analyses using: (a) a linear-elastic model; (b) a linearly elastic-perfectly plastic model with the Mohr-Coulomb yield criterion; and (c) the Purdue sand model and the linearly elastic-perfectly plastic model with the Mohr-Coulomb yield criterion (Han et al., 2019)

Taking piles again as an example, teaching an analysis that ignores the shear strain localization along the pile shaft will be ineffective in that the value of pile shaft resistance cannot be calculated with any accuracy using such an analysis. Thus, one could teach using directly the results of analysis for piles in sand (e.g., Han et al., 2017; Loukidis & Salgado, 2008) or clay (e.g., Basu et al., 2014; Chakraborty et al. 2013a) that do account for localization and realistic soil response. For undergraduates, the teaching might consist of presenting the equations, explaining why they were formulated with those particular forms, and then having the students apply the equations directly to design problems. At the graduate level, one could go beyond that, and ask the student to read the papers, reproduce results and apply them to more challenging design problems.

As a final illustration of how strain localization can be included in our teaching, we turn again to the pile group example. It is advantageous to introduce students to these problems using the classical papers assuming linear elastic soil (Poulos, 1968; Randolph & Wroth, 1979), which facilitate understanding of the concepts of group pile interaction and group efficiency, but then share with them new results (Han et al., 2019; Salgado et al., 2017) that show that the interaction between the piles is considerably reduced when shear strains localize along the shafts of the piles.

5 Conclusions

The pioneers of soil mechanics faced some difficult choices. Faced with hard challenges and limited knowledge, they made some decisions on how to model soil and analyze the boundary-value problems of soil mechanics that have had a significant impact on how the discipline and its teaching evolved.

The three choices that were made that are highlighted in the paper are the use of Terzaghi's "ideal sand" and "ideal clay" models, the use of an associated flow rule with these models, and the neglect of shear strain localization in the solution of boundary-value problems. These choices led to some confusion regarding how soil responds to load, left engineers at a loss as to how to estimate shear strength parameters, and produced solutions to core problems in soil mechanics – such as the bearing capacity problems, the axial loading of a pile or the response of pile groups – that are either incorrect or unrealistic.

The discipline has overcome these initial modeling choices, and there are now better models and better theories for modeling both soil – the material – and the various engineering problems of interest. These better approaches need to be included in textbooks and shared with the community. With the right way of presenting these newer theories, it is possible to teach them to undergraduate, as well as graduate students.

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Invited author's bio

Rodrigo Salgado, Purdue University, USA

Rodrigo Salgado is the Charles Pankow Professor in Civil Engineering at Purdue University. He holds a Ph.D. and an M.S. degree from the University of California, Berkeley, and an engineering degree from the Federal University of Rio Grande do Sul (UFRGS), Brazil. Prof. Salgado is the author of 120 journal publications, 81 conference publications, 30 technical reports and the text The Engineering of Foundations. He has supervised 27 Ph.D. students to completion and has been the recipient of prestigious awards, including the ICE Geotechnical Research Medal (2015), the Outstanding Reviewer Award from Computers and Geotechnics (2015), the IACMAG Excellent Contributions Award (2008), the Prakash Research Award (2005), the ASCE Huber Research Prize (2004), and the ASCE Arthur Casagrande Award (1999). He has also been an invited participant of the U.S. and U.S.-China editions of the National Academy of Engineering Frontiers of Engineering Symposium. He is a Fellow of ASCE and has been inducted into the GeoAcademy. He is Editor in Chief of the ASCE Journal of Geotechnical and Geoenvironmental Engineering and serves on the editorial boards of several top journals. Prof. Salgado's interests lie in geomechanics, foundation engineering, computational mechanics, constitutive modeling and offshore and energy engineering.

Curricula: Undergraduate, (Post)Graduate, Doctoral

Assessment of Graduate Attributes Development in Two Foundation Engineering Design Courses

Y. Nazhat

Department of Civil Engineering, Faculty of Applied Science, the University of British Columbia, Vancouver, Canada

ynazhat@civil.ubc.ca

ABSTRACT: This paper presents a framework, guidelines and findings with respect to assessing graduate attributes in two foundation engineering design courses at the University of British Columbia (UBC). These are both final year technical elective courses within the Civil Engineering undergraduate program at UBC. Canadian engineering programs are required to instil, assess and report on 12 graduate attributes with respect to their students. Of these attributes, these two courses focus on the problem analysis, engineering design, and professionalism attributes. The framework that is described includes the degree structure, the graduate attributes and component indicators, the assessment process and methodology, the data and results obtained, and the resulting continual improvements with respect to the graduate attribute process, the curriculum and student development. Data collected shows improved levels of accomplished skills by students with respect to the various indicators, and show significant increases in student perceptions of teaching quality, and overall satisfaction with the coursework experience. The framework and guidelines as described are contributing to the continual improvement of UBC's Civil Engineering program, and they should be useful to other engineering programs that are planning, or have commenced with, a graduate attributes assessment process. Assessing the development of graduate attributes in specialized elective design courses plays an important role in relation to quality assurance, continual improvement and reporting, and assure alignment between approved and as-taught curricula of problem-based-learning courses.

Keywords: Foundation engineering, graduate attributes, indicators, assessment, program improvements

1 Introduction

Learning outcomes are key to quality education. The modern engineering profession constantly deals with uncertainties and challenging demands from clients, authorities, and the general public. Today's engineers must cope with continual technological changes as well as organisational challenges in the workplace and within their communities. Additionally, they must cope with the economics of engineering practice in the modern world, as well as the legal consequences of the professional decisions they make. Educators occasionally are confused between learning outcomes and learning objectives as the two terms were used interchangeably in education literature. Fiegel (2013) distinguishes learning outcomes as being statements of what students are expected to be able to demonstrate as a result of learning, as opposed to learning objectives that are statements of teacher intention (or goals) for a specific topic, and how particular learning outcomes are linked to courses' materials. As a result, the approach and emphasis in engineering education and accreditation criteria for engineering programs in recent years have been shifted from objective-based/input-based education (number of classes taken, study time and student workload) to outcome-based concepts (Mills & Treagust, 2003; Chung, 2011), meaning what students have learned and are able to do by the time of graduation and beyond (EA, 2017; ABET, 2019).

Changes in the Canadian accreditation requirements in professional engineering have changed the way UBC evaluates its engineering programs. Assessment of students' Graduate Attribute is used to answer the key question about how are students' performances match specified expectations. It also identifies gaps between perceptions of what institutions teach and the actual knowledge, skills, and views students develop program-wide. The quality of an engineering program now depends not only on the objectives and attributes to be assessed but also on the program's teaching and learning practices and assessment of students, including confirmation that the graduate attributes are accomplished.

The modern accreditation approach based on learning outcomes shifts emphasis away from "what is being taught" to "what is being learned". Engineering programs are now required to demonstrate that their graduates are achieving a set of specific learning outcomes with specific requirements about design education, economics, project management, ethics, and industry relevance of their programs. This shift took place in Canada in 2012 when the Canadian Engineering Accreditation Board (CEAB) introduced the outcome-based assessment for the accreditation of Canadian engineering programs (CEAB, 2012). The CEBA accreditation criterion, which includes twelve graduate attributes, emphasizes continual curriculum improvement by engineering programs to monitor and improve their internal process. According to this criterion, each engineering program in Canada must have a system in place for continuously assessing these attributes and using the assessment results to improve their programs. It is a requirement for accreditation that the curriculum criteria be met by all students. This aspect of the engineering accreditation system assures Engineers Canada that graduates meet the academic requirements for licensure by engineering regulatory and licensing bodies without requiring additional technical examinations.

2 CEAB Accreditation

Graduate attributes describe what students are expected to know and can do when they graduate. For each attribute, there is a set of indicators that represent the knowledge, skills, attitudes, or behavior that students should be able to demonstrate and indicate competency level related to the attribute. They measure the achievement of the attribute. CEAB graduate attributes and indicators are called, student outcomes and learning objectives, respectively. There is an important international aspect to Canada's accreditation system. Accreditation bodies in countries who are signatories to the Washington Accord (IEA, 2014) use an outcomes-based assessment that allows substantial equivalency of graduates from relevant organizations of the signatory countries, including Canada.

The Faculty of Applied Science at UBC seeks to assure that, at the time of graduation, engineering graduates possess the twelve attributes identified by the Canadian Engineering Accreditation Board (CEAB). These relate to:

1. A knowledge base for engineering
2. Problem analysis
3. Investigation
4. Design
5. Use of engineering tools
6. Individual and team work
7. Communication skills
8. Professionalism
9. Impact of engineering on society and the environment
10. Ethics and equity
11. Economics and project management
12. Life-long learning

The CEAB criteria are assessed with respect to the 12 graduate attributes and 8 assessment elements. The 8 assessment elements are as follows:

Graduate Attributes:

1. Organization and engagement
2. Curriculum maps
3. Indicators
4. Assessment tools
5. Assessment results

Continual Improvement:

6. Improvement process
7. Stakeholder engagement
8. Improvement actions

CEAB looks for a linkage between the outcomes assessment process and the official curriculum overseeing through programs' specialised groups.

3 Assessment Process

The development of a system for assessing graduate attributes in the Department of Civil Engineering at UBC started in 2014. The plan is executed by two committees within the Department; the Program Improvement Committee (PIC) and Curriculum Committee (CC). PIC develops the Department's graduate attributes and their continual improvement process (GA/CI) as required by the CEAB and coordinates the implementation of the GA/CI process and intended curriculum improvements with the Curriculum Committee. The flow of the assessment process adopted by UBC is shown in Figure 1.

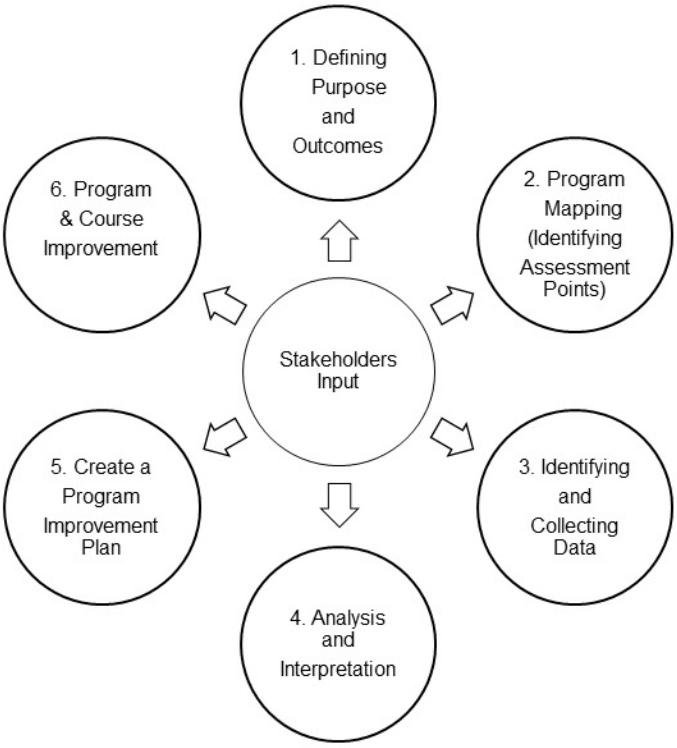

Figure 1. Assessment process adopted by UBC

All activities are performed at the department level. Activities 1 and 6 are conversed with the Faculty of Applied Science to be ultimately sanctioned by the University. Feedback from faculty members, stakeholders, and CEAB are pursued when identifying or revising program objectives and/or plans for program improvements. The department's PIC chair performs the following duties throughout the process of collecting and analysing the data for the accreditation process:

- Develop and monitor the assessment process.
- Meet with stakeholder groups and representatives to provide guidance and answer questions
- Meet with Faculty and University representatives.
- Prepare standard course syllabi and rubrics for the program's courses.
- Meet with the assessment instructors at the start of each term to explain significant assessment aspects.
- Act as a focal point of contact regarding issues that may arise during the assessment process.
- Prepare templates for responding to CEAB questionnaire sections related to the assessment.
- Develop an assessment report for submission to CEAB.

The Department PIC Chair leads the assessment process in collaboration with the program's instructors and the Faculty of Applied Science. The PIC chair acts as a focal point of contact regarding issues that may arise during the assessment process and develops the department's assessment report for submission to CEAB.

4 Assessment Elements

4.1 Graduate Attributes (GA) and Indicators (IN)

The program curriculum map is a matrix with rows that represents the curriculum courses (learning experiences) and columns are the 12 CEAB attributes. Table 1 shows the curriculum map of the foundation design courses analysed in this work. The map indicates to what degree each attribute has been developed (Emphasized, Introduced, Utilized and Not required) in these courses.

Table 1. Curriculum Map of CIVL 410 & CIVL 411 Foundation Engineering Courses

Course	CEAB Graduate Attributes*											
	1	2	3	4	5	6	7	8	9	10	11	12
CIVL 410	E	E	E	E	E	E	E	I	E	E	E	E
CIVL 411	E	E	E	E	N	E	E	U	E	U	I	E

* E: Emphasized (taught and assessed)
I: Introduced (appeared in the course but not assessed)
U: Utilized (required for the course but not taught)
N: Not required by the course

The assessment of each of CIVL 410 and CIVL 411 attributes is conducted by the course instructors. The assessment methods for GA 2 and GA 7 in these courses are listed in Table 2.

4.2 Analyzed Foundation Engineering Courses

CIVL 410 "Foundation Engineering I" and CIVL 411 "Foundation Engineering II" are the two fourth-year technical elective foundation engineering courses in the undergraduate Civil Engineering program at UBC. They are offered during the fall and spring terms respectively.

The objective of CIVL 410 is to give students an opportunity to apply geotechnical engineering concepts by working on design-oriented assignments that are structured to reflect the work in a geotechnical consulting company. Students who go on to specialize in geotechnical engineering will plan, implement and report on such evaluations and will guide design engineers in the use of their recommendations. Students are given field and testing data from geotechnical case histories.

Since geotechnical engineers derive great benefit from the study of case histories as they learn from the experience of others in dealing with similar problems in similar ground conditions, the partner foundation design course, CIVL 411, consists of case histories delivered by geotechnical practitioners. Students are required to prepare a two page summary for each of the 30 presentations covered during the course.

4.3 Assessment Methods

Assessment methods are generally categorized into two categories (Spurlin, 2008): direct and indirect methods. Direct methods, such as oral exams or final written exams, will allow the direct examination or opinion of student knowledge or skills associated with the subject indicators, while indirect methods such as exit surveys or interviews assess views or self-reports that indicate student abilities. CEAB requires that each attribute is assessed by at least one direct method, but a reflective assessment would use both methods of assessment.

Table 2. Direct Assessment Methods for Presented Graduate Attributes

Attribute	Indicator	CIVL 410 Direct Assessment Tools	CIVL 411 Direct Assessment Tools
2. Problem analysis	2.1 Identify and formulate problems 2.2 Analyze and solve problems 2.3 Evaluate solutions	Test questions in quizzes, assignments and final exams that involve problem analysis	Test questions in quizzes & final exams
7. Communication Skills	7.1 Comprehension 7.2 Writing 7.3 Presentations	Written assignments	Written summary reports of case studies

Student and employer surveys and focus groups are developed and used by all UBC programs. The Civil Engineering department conducts employers' consultation and engagement (either via co-op or employers in particular companies and sectors that have direct contact with UBC graduates who are one year to three years after graduation from the Civil Engineering program). Student consultation and engagement through meeting with representatives of the graduating class each year are carried out to collect suggestions for improvement regarding the department's coverage of the various indicators, and whether students have specific suggestions regarding the degree curriculum and other improvements for the program. This is to be followed up with the on-line exit survey directed to each year of the program. The exit survey is distributed to all participating students at the end of the university term. The survey includes student opinion questioners that focus on learning experiences and skill areas. Students are asked to rate each of the statements on a scale of 1 to 5. Besides, students are given the opportunity to provide feedback about the course and comment on their learning experience at UBC.

4.4 Direct Assessment

To evaluate attributes assessment results, it is important to consider a threshold (TH) and a target (T) grade for each course in the program. Thresholds and targets are discussed with the courses' instructors and then regulated by the department PIC. The threshold is the minimum acceptable level of performance on a given indicator, while the target is the intended level of learning proficiency for that indicator (Meyer et al., 2010). If the performance of an indicator is less than its threshold, this means investigation is required to determine its basis, and to suggest means of needed improvement measures. Usually, the improvement efforts will focus on those indicators first, followed by indicators that are below the target performance. The following grades present the civil engineering program goal expectations:

- EE - Exceeds expectations (100 - 90%)
- ME - Meets expectations (89-76%)
- MME - Minimally meets expectations (75-66%)
- DME - Does not meet expectations (65-50%)

For fourth-year courses, grades of 65% and 90% represent the threshold (does not meet expectations) and the target (exceeds expectations), respectively. Figure 2 shows the threshold and target grades relative to CIVL 410 marks from one of the course assignments.

4.5 The Program Assessment Schedule

Multiple courses from the Civil Engineering program are assessed during each year during the six-year accreditation cycle. Each of the twelve CEAB attributes is assessed annually during the cycle. This provides a few rounds of refinement on each attribute prior to any given CEAB visit and allows witnessing improvements associated with detected incompetent attributes during the accreditation cycle. However, the Civil Engineering program does not report on any assessment from its technical elective courses, on the grounds that the assessment process focusses on a “critical” path based on all students, who take the program core courses.

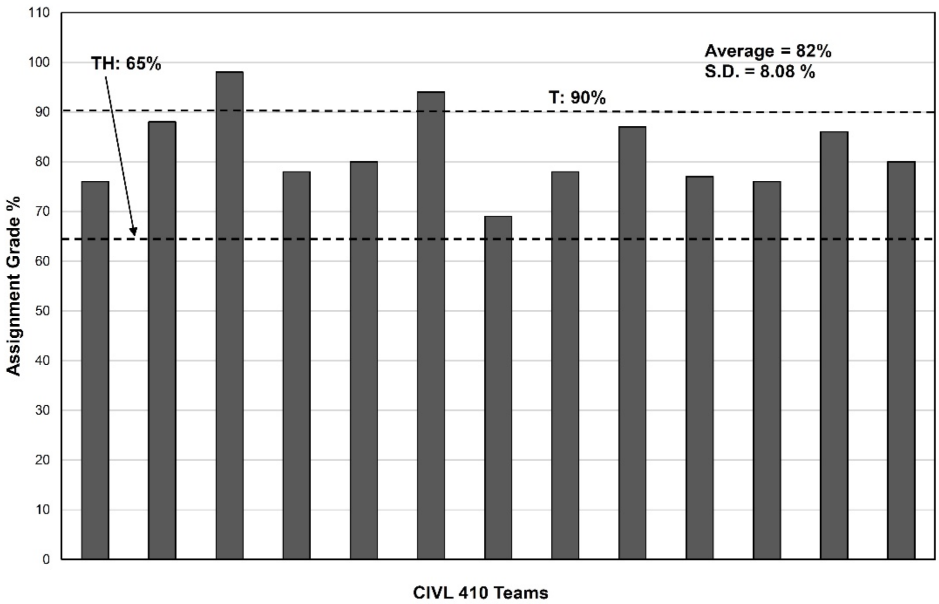

Figure 2. Example of year 2018 class (13 teams of 6 students each) performance in one of CIVL 410 assignments

5 Data Assessment and Results

In this study, CIVL 410 assignments and CIVL 411 summary reports were used to evaluate selected attributes for the Civil Engineering program. The analysis results for GA2 - Problem Analysis skills attribute, and GA7 - Communication Skills attribute, as outlined in Table 2, are shown in Figures 3 and 4, respectively. GA2 has three indicators: IN2.1 (identify and formulate problems), IN2.2 (analyse and solve problems), and IN2.3 (evaluate solutions), while indicators for GA7 are: IN7.1 (comprehension), IN7.2 (writing) and IN7.3 (presentations). Deliverables from these courses’ were evaluated by faculty members and reported to the program PIC. Using the courses’ rubrics, the evaluator graded each indicator and assigned a percentage value as per assigned rubrics. The results show the percentages of students’ achievements exceeding, meeting, minimally meeting and not meeting expectations for each selected indicator. Rubrics of CIVL 410 (including assessment criteria of its assignments) and CIVL 411 are presented in Appendices A and B, respectively.

Figures 3 and 4 show that students’ overall performance are improving during CIVL 410 for the competency of GA 2 from assignment 1 (DME: 9.1% in 2017 and DME: 30.7% in 2018 – i.e. below specified threshold) to assignment 3 (DME: 0% of students not meeting expectations in both years) over the 8 weeks these assignments are apart. The decline in the overall percentage of students exceeding expectations (below target) with respect to GA 2 in Assignment 3 could be related to the more challenging nature and advanced scope of work of this assignment.

The assessment results shown in Figures 3 and 4 are consistent or better than average students’ performance with respect to the corresponding indicators of GA 2 from second-year and third-year core courses of the Civil Engineering program (EE:18%, ME: 40%, MME: 37% and DME: 5%). However, continual monitoring of percentages of students not meeting expectations in assignment 1 in future years would be very helpful in assessing whether improvement in the earlier years of the Civil Engineering program is needed.

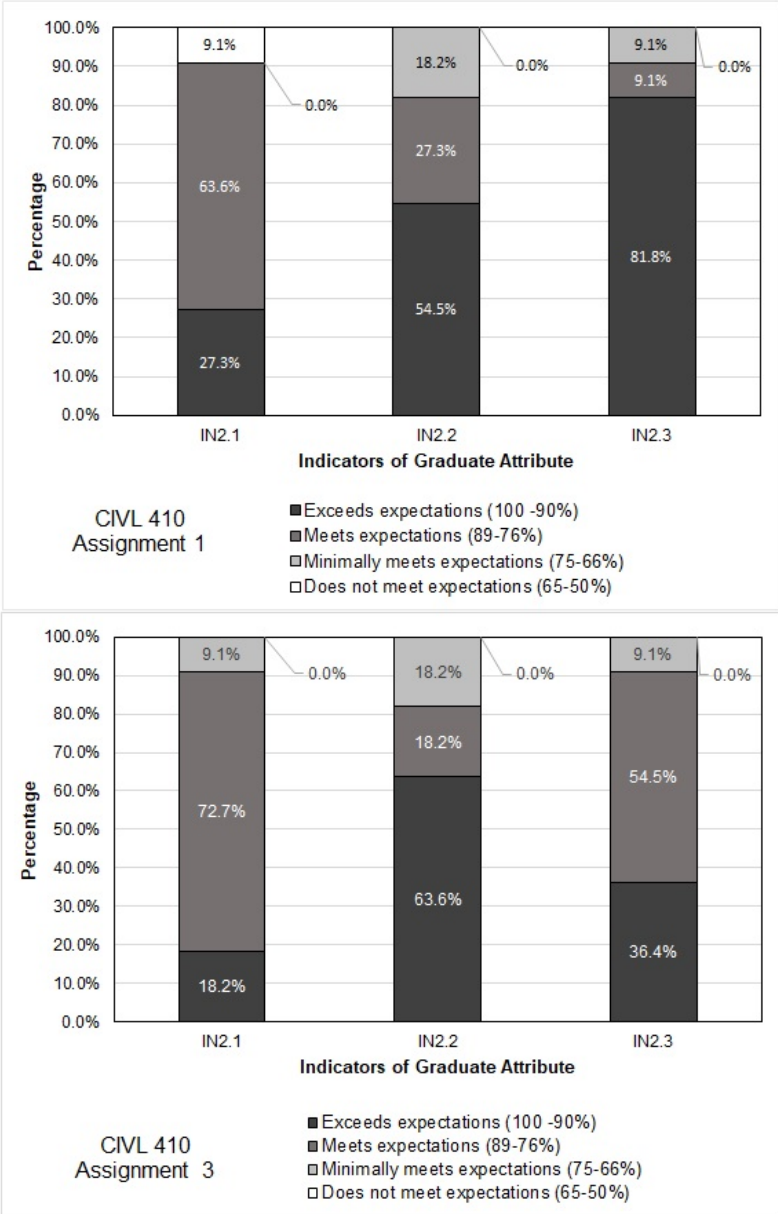

Figure 3. Students' performance in year 2017 for "Problem Analysis" from assignment 1 (week 5 of the term) and assignment 3 (week 12 of the term) using CIVL 410 rubric

The assessment of students' communications skills in CIVL 411 class are presented in Figure 5. The results indicate that 4 - 7% of students not meeting the course expectations. The average of these results is slightly higher than the program-wide expectation of DME of 5% in fourth-year classes. This could be related to the advanced and complex nature of the case histories delivered by geotechnical practitioners to CIVL 411 students. Nevertheless, these findings suggest that more emphasis should be placed by the program PIC and CIVL 411 instructor to address such deficiency and make changes in the way this course is delivered and possibly some other improvements to the degree curriculum (the process has already started) that would advance students' communications skills throughout the previous three years of the program.

6 Conclusions

Focusing on learning outcomes is essential to impart diagnosis and advance teaching processes and student learning. Engineering programs in Canada are expected to demonstrate compliance with the

CEAB graduate attribute criterion with learning attributes and continual improvement measures that form the basis for their accreditation decisions.

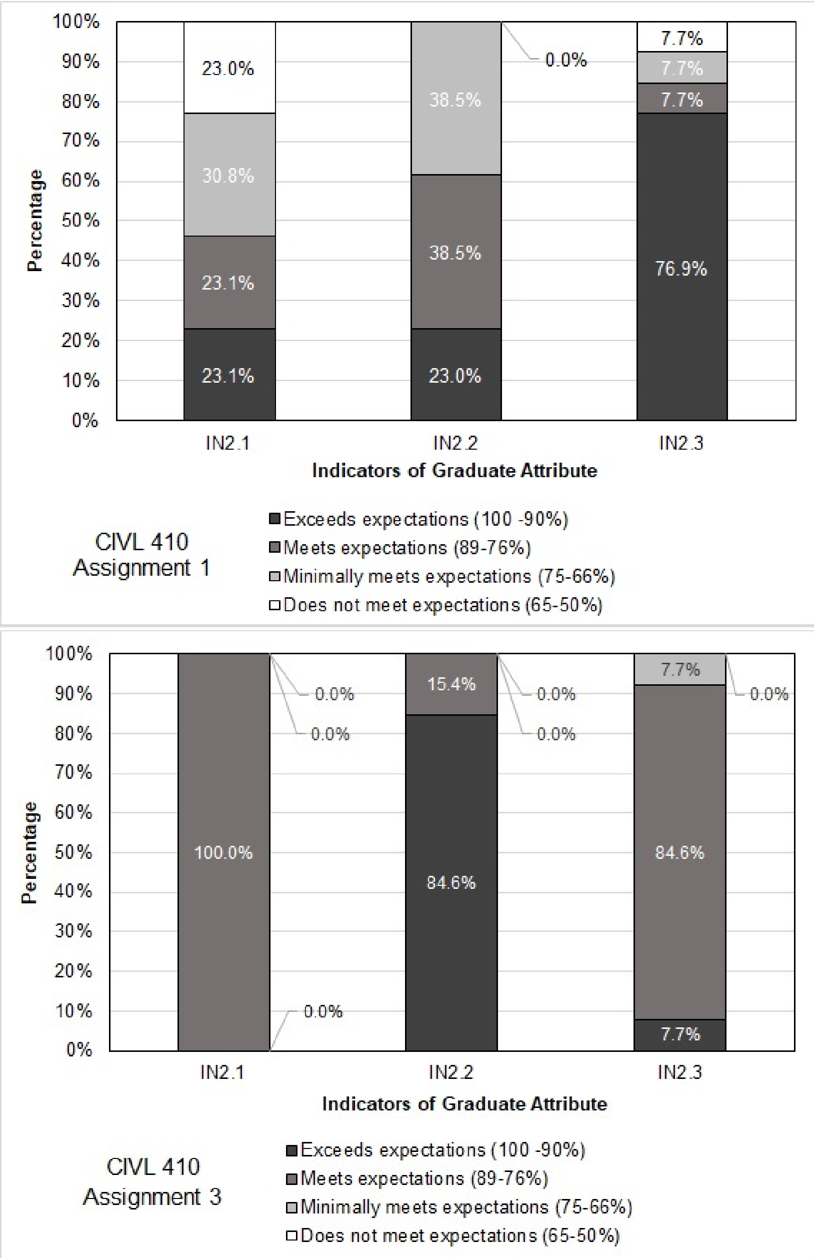

Figure 4. Students' performance in year 2018 for "Problem Analysis" from assignment 1 (week 5 of the term) and assignment 3 (week 12 of the term) using CIVL 410 rubric

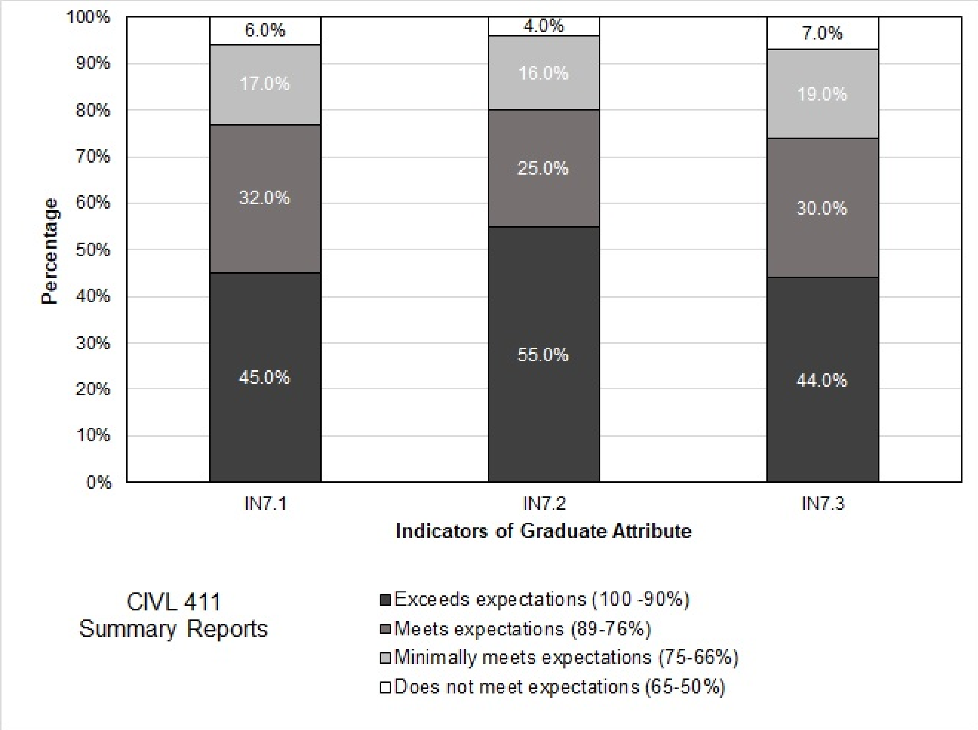

Figure 5. Students' performance in year 2018 for "Communication Skills" attribute using rubric for CIVL 411 summary reports

Students' performance in the investigated UBC fourth-year technical elective foundation engineering courses suggests signs of improved trends in students' learning skills of the selected indicators with reference to students' achievements during previous second and third years of the program.

It is recommended to regularly assess attributes performance of a few selected technical elective courses from the program every year or every second year, whether or not these courses are selected by the department for the assessment report according to the program curriculum map and schedule. This will further highlight whether the improvement of particular attributes in the earlier years of the Civil Engineering program is necessary. Suggestions for improvement in student performance with respect to GA2 "Problem Analysis" indicators 2.1 (Identify and formulate problems) and 2.4 (Evaluate Solutions) to be further emphasized in some third-year core courses; proposing CIVL 311 "Soil Mechanics II" being the prerequisite course of the investigated foundation engineering courses.

It is also recommended to continue improving the delivery of CIVL 410 and CIVL 411 courses with emphasis on teaching and assessing student performance with respect to the non-technical range of graduate attributes relating to teamwork, ethics, life-long learning, design, and professionalism that are challenging to instil, assess and report on. Results from these assessments can contribute to the program assessment and improvement accreditation reports.

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Appendices

Appendix A – CIVL 410 Rubrics

The marks for CIVL 410 are assigned as follows:

Evaluation Method	Marks %
Individual quizzes	15
Team assignments 1-3 (each assignment contributes 10% of the overall CIVL 410 grade)	30
Peer evaluations (reflect individual tutorials attendance, quality and extent of individual's contribution in team assignments) 10% for PE1 and 5% for PE2	15
Final exam	40
TOTAL	100

CIVL 410 assignment 1 assessment criteria

Task	Mark %
Developing a representative geotechnical model	30%
Selecting representative values of soil properties & discussion of design issues	40%
Liquefaction assessment & recommendations	20%
The overall presentation	10%
Total	100%
Total scaled to 10%	10%

CIVL 410 assignment 2 assessment criteria

Task	Mark %
Part I - Ground improvement using preloading solution - Calculate the likely settlement and the time required for completion of preloading.	30%
Part II - Site preparation scheme by cut and fill approach (engineered fill replacement). Design pad footings that satisfy the following criteria: • Maximum allowable total settlement of the foundations is 40 mm • Maximum allowable distortion due to differential settlement between columns is 1/500 of the span between columns.	40%
Part III – Discuss alternative ground treatment techniques	20%
The overall presentation	10%
Total	100%
Total scaled to 10%	10%

CIVL 410 assignment 3 assessment criteria

Task		Mark %
Design Task 1: Considering suitable basement construction alternatives and briefly discuss advantages and disadvantages.		25%
Design Task 2: The geotechnical design of your selected solution by:		
(1) Terzaghi and Peck (1967) apparent earth pressures and hinge method	(20%)	40%
(2) WALLAP software - Limit Equilibrium Analysis and CP2 methods of calculating Factor of Safety	(20%)	
Understanding risk involved and identifying the geo-hazards that are associated with the proposed basement construction scenarios.		25%
The overall presentation		10%
Total		100%
Total scaled to 10%		10%

Appendix B – CIVL 411 Rubric

The marks for CIVL 411 are assigned as follows:

Evaluation Method	Marks %
First set of Summary reports (abstracts)	5%
Quiz	5%
Second set of Summary reports (abstracts)	10%
Casebook submission	40%
Final Exam	40%
TOTAL	100%

Summary reports (abstracts) to be submitted electronically twice during the term on dates shown in the course schedule. Students' notes for each presentation should also be submitted in electronic format. During the marking process, all summaries and notes will be reviewed.

Marks will be deducted if:

- The presenter, topic and handouts are incorrectly identified;
- There is little or no content from the lecture (as opposed to information in the handouts);
- If significant portions of the summary are just copied from the handouts;
- If there is no evidence of reflection to identify key points of the geotechnical lessons learned;
- Over word limit.

Summary reports are to be organized into a casebook that would serve as a useful tool for future reference. Students must create a digital casebook (folder structure) containing all their summaries, classes' notes, lectures' slides and handouts. The casebook will be submitted by the date of the final exam.

Author's bio

Yahya Nazhat, University of British Columbia, Canada

Dr. Yahya Nazhat joined the Department of Civil Engineering as an instructor in 2014. He worked as a Civil & Geotechnical Engineer in research, construction and consulting practice from 1983-2009 before pursing Ph.D. research during 2009 to 2013 from the University of Sydney (Australia). His PhD had a focus on Behaviour of Sandy Soil Subjected to Dynamic Loading. Having held senior engineering and management positions in industry in both Australia and the Middle East, Dr. Nazhat has long experience in detailed geotechnical investigation and geotechnical studies associated with major infrastructure projects including highways, tunnels, high-rise buildings, airports and rail projects. He has years of experience in piling and deep foundation including design, construction and pile testing. He is a registered Professional Engineer in BC, Canada, a Chartered Professional Engineer in Australia, and a Fellow of the Institution of Engineers, Australia.

Coursework: Laboratory, Field, Project-based, Numerical Methods

Development of an Advanced Field and Laboratory Testing Course for Geotechnical Engineering Students

N. Derbidge & G. Fiegel

California Polytechnic State University, San Luis Obispo, USA
nderbidg@calpoly.edu, gfiegel@calpoly.edu

ABSTRACT: The paper describes the development of student learning outcomes, activities, and assignments for an advanced geotechnical engineering course focused on field and laboratory testing. The learning outcomes were developed using Bloom's Taxonomy. Some of these outcomes include: log a borehole and prepare final borehole logs; analyze relationships between stress history and shear strength for a local site; compare side-by-side SPT/CPT results; and evaluate the effects of sample disturbance on laboratory consolidation and strength test results. During the course, the authors work with local contractors, consultants, and students to excavate borings, perform in situ tests, and collect soil samples at a nearby site. Throughout the term, the students perform laboratory tests on collected soil samples and develop a site characterization report. In the paper, the authors discuss their experiences developing and implementing field and laboratory learning activities. The authors reflect on their experiences working together to develop and teach the course. Insight is offered on addressing logistics for laboratory-intensive courses and teaching advanced geotechnical concepts.

Keywords: field testing, site characterization, sampling, laboratory, learning outcomes

1 Introduction

The paper describes our experiences developing and teaching an advanced geotechnical engineering course on field and laboratory testing and site investigations. We provide details regarding format and structure of the course as well as the intended audience. In addition, we list and describe the course learning outcomes. These outcomes provided guidance for the authors during the preparation of lesson plans, laboratory activities, field activities homework assignments, formative assessments, and summative assessments. We have taught this course every year since 2016. The course is offered at the graduate level at California Polytechnic State University, San Luis Obispo (Cal Poly). However, enrolment typically includes an even mix of undergraduate and graduate students. The paper outlines the laboratory and field learning activities we developed, assessed, and improved over the past four years. Also described are course activities and assignments. We conclude the paper with discussions of lessons learned and strategies for implementing similar learning experiences at other institutions.

2 Background

2.1 Program, Enrolment, and Format

We teach the subject course for seniors and graduate students studying civil engineering and related disciplines. At Cal Poly, the academic year includes four quarters, each eleven weeks long. Course instruction takes place over a ten-week period. Instructors administer their final examinations during the eleventh week of the term. The subject course represents a 4-unit lecture-laboratory offering. Each week, the students meet with their instructor in the classroom (i.e., lecture) for two hours and in the laboratory for six hours. A typical course schedule will have the 2-hour lecture assigned Tuesday morning and the laboratory assigned as two 3-hour sessions on Tuesday and Thursday afternoons or as a single 6-hour session on Thursday afternoon. The subject course is an optional elective in the civil engineering program. Recent enrolments in the course have ranged between 15 and 20 students.

We divided the course into the primary subjects or "learning modules" listed in Table 1. We selected these topics based on an assessment of knowledge and skills needed for undergraduate and graduate students entering geotechnical engineering practice, particularly in California. We address the topics in the order presented in Table 1. Students learn about site investigations and the process of developing geotechnical recommendations from site reconnaissance to field testing to laboratory testing to report preparation. Within the laboratory portion of the course, we provide time for field drilling, sampling, cone penetration testing, and extensive laboratory testing. Drilling and cone penetration testing are performed on campus, in collaboration with local contractors. During a typical field investigation, we excavate two to three borings and complete one to three cone penetration soundings.

Preparation of the preliminary geotechnical engineering report represents the primary objective of our project-based learning approach to the course. Students in the course work together in groups of 3 or 4 persons to complete their assignments. Throughout the term, instruction and learning activities support the completion of the project. Additionally, we include supplemental activities designed to introduce advanced concepts in consolidation and shear strength theory. The supplemental activities also assist us in "training" the students to develop field and laboratory best practices.

Table 1. Primary Course Subjects or Learning Modules

Number	Learning Module	Approx. Course Fraction
1	Index Testing and Soil Classification Review	5%
2	Site Reconnaissance and Desk Studies	10%
3	Subsurface Investigations, Exploration, and Sampling	10%
4	In Situ Testing: Cone and Standard Penetration Tests	10%
5	Advanced Consolidation Testing and Concepts	15%
6	Advanced Shear Strength Testing and Concepts	20%
7	Stress History and Behavior of Clay Soils	10%
8	Undrained versus Drained Loading and Stress Paths	10%
9	Expansive Soil Behavior and Evaluation	10%

During the learning modules, we present terminology, definitions, concepts, theories, problem-solving techniques, testing procedures, design guidelines, and other information. We support student learning using in-class lessons, laboratory exercises, supplemental notes, technical articles, and textbook readings. The in-class lessons involve considerable work on the chalkboard (or white-board) and include frequent student questioning (Estes et al., 2004). The supplemental notes include learning outcomes, details on important concepts, problem solving tips, case histories, and examples prepared by the authors. The students download these notes for free from the course website. We assign research and technical articles to support the supplemental notes, in-class lessons, and laboratory work. We use freely available, state-of-the-practice industry design manuals as the primary course texts (e.g., Mayne et al., 2001; Robertson and Cabal, 2015; Sabatini et al., 2002; Samtani et al., 2006).

2.2 Prerequisites and Prior Learning

Graduate students may enroll in the subject course as long as they demonstrate previous learning related to geotechnical analysis and design. Undergraduates who wish to enroll need to complete a prerequisite junior-level course on introductory geotechnics and analysis. A laboratory that accompanies this course includes experiments on soil index testing, hydraulic conductivity, shear strength, and others. After completion of the introductory course, undergraduates must also complete a prerequisite senior-level analysis and design course on shallow foundations. Students in this course synthesize knowledge from previous courses and begin to develop their geotechnical design skills. The second course includes a learning module on settlement and intermediate concepts related to consolidation theory.

2.3 Learning Outcomes

Course learning outcomes define what the students should know and be able to do upon completion of a course topic (Donnelly and Fitzmaurice, 2005; Fiegel, 2013). We identified essential knowledge and skills for the learning modules listed in Table 1. We then developed matching learning outcomes. These learning outcomes are defined in the supplemental notes and on the course website. We reference these outcomes throughout the course to orient the students to important concepts.

Bloom’s original taxonomy of skills for the cognitive domain included six levels of understanding of a concept or topic, ranging from ‘knowledge’ at the lowest level to ‘evaluation’ at the highest level (Bloom et al., 1956). Anderson et al. (2001) revised Bloom’s taxonomy by proposing a framework with ‘Knowledge’ and ‘Cognitive Process’ dimensions. The latter dimension closely resembles the original taxonomy: it represents a continuum of increasing cognitive complexity with six categories (or levels) spanning lower-order to higher-order thinking skills. The revised taxonomy includes the following six levels: (1) remember; (2) understand; (3) apply; (4) analyze; (5) evaluate; and (6) create. The revised version of the taxonomy reflects advances in educational research since Bloom’s original work and provides a tool for instructors developing curricula and assessing performance.

We used the revised taxonomy when developing learning outcomes for the subject course. Table 2 shows an action verb for each outcome along with an estimated level of achievement in the cognitive domain. For a senior or graduate level engineering design course, we believe it is essential to identify several outcomes for achievement levels five and six (i.e., “evaluate” and “create”).

Table 2. Learning outcomes for the subject course

Action verb	Outcome*	Level
Classify…	soils during a drilling operation using visual-manual procedures	Analyze
Log…	a borehole and prepare final borehole logs	Apply
Collect and test…	soil samples for classification, strength, and compressibility	Apply
Compare and contrast…	test results with findings in peer-reviewed scholarly works	Evaluate
Interpret and compare…	the results of undrained triaxial shear tests	Analyze
Assess…	the swell potential of a soil	Evaluate
Develop…	a stress history profile for a soil site	Analyze
Develop…	relationships between stress history and shear strength for a soil site	Evaluate
Appraise…	the applicability of SPT and CPT empirical correlations for a soil site	Evaluate
Classify…	soil behavior type using CPT measurements	Analyze
Compare…	side-by-side SPT and CPT results	Analyze
Determine…	the effects of sample disturbance on laboratory test results	Evaluate
Prepare…	a preliminary Geotechnical Engineering Report for a soil site	Create

* - SPT = Standard Penetration Test; CPT = Cone Penetration Test.

2.4 Geotechnical Engineering Experience

Prior to designing and teaching the subject course, we collaborated in developing course content and activities for our program's introductory geotechnical engineering course and laboratory. As we developed and piloted different versions of the subject course, we undertook a multi-year plan to upgrade and modernize our laboratories. In support of this effort, we focused on purchasing equipment and implementing renovations that would provide opportunities for project-based undergraduate student learning and instruction as well as advanced research by faculty and graduate students.

We were confident that we could transform the subject course because of our previous collaboration together, our past success working with local engineering consultants and contractors, and our past professional experiences in academia and engineering practice. Teaching a course like this requires considerable time and effort, where an instructional team of faculty and/or graduate assistants is better prepared for success than a single individual. In addition, success while teaching in the field and laboratory requires the instructional team to have a broad understanding of geotechnical engineering concepts, design methods, field and laboratory testing procedures, instrumentation, and equipment.

We have considerable experience teaching and working in geotechnical practice, and specifically in laboratory and field-testing environments. Having taken a somewhat unique career path and journey, our lead author worked as a geotechnical consultant in California for over 15 years before transitioning to teaching and academia. His experience includes dozens of projects such as highway improvements and bridges, commercial developments, nearshore structures, slope reconstructions, and a variety of public works projects. He also served as construction services and laboratory manager. As laboratory manager, he was responsible for sophisticated and routine geotechnical testing services for numerous offices in California. In his current role, our lead author holds a dual appointment: (1) serving as an instructional support technician for our geotechnical, materials, structures, and pavement laboratories; and (2) teaching geotechnical and materials engineering courses. Forming an instructional team with broad technical and practical experience was essential for success in this course.

3 Course Activities and Assignments

3.1 Site Characteristics and Accessibility

We teach at an institution that supports a large agriculture and environmental sciences college. Therefore, available outdoor spaces (e.g., crops fields and rangelands) provide opportunities for field work and investigation. Several sites on campus are underlain by alluvial deposits consisting of fine- and coarse-grained sediments ranging in thickness from 5 to 25 meters. The fine-grained soils consist primarily of normally to slightly overconsolidated lean clays, while the coarse-grained soils are typically medium to coarse sands and gravels. These deposits are underlain by significantly weathered and relatively weak sedimentary bedrock (e.g., sandstone, claystone, siltstone). Groundwater at the sites fluctuates throughout the year, but is typically found within about 5 meters from the ground surface.

Available sites on campus provide an ideal environment for instruction, as they permit hollow-stem auger drilling, standard penetration testing, thin-walled tube sampling, cone penetration testing, and groundwater monitoring. Open spaces in the vicinity of an exploration location allow us to create field "classrooms" with tables and dispersed student work stations (see Figure 1). In addition, the sites are easily accessible - students typically walk or ride their bikes to the sites - and relatively free of utilities. Importantly, we coordinate our field efforts with utility locating services; however, the learning exercise is commonly trivial and uninteresting since work takes place primarily in undeveloped agricultural fields.

Figure 1. Field drilling and instruction on borehole logging

Overall, the success of the subject course depends, to a certain extent, on free and repeated access to these field experiment sites. Although uncertainty is expected during any geotechnical investigation, our continued work with these campus sites has limited some of the variables associated with field work and allowed us to focus on teaching and instructional design.

3.2 Benchmark Homework Assignments

As noted, students work in teams to produce a preliminary geotechnical engineering report. The report is due at the end of the ten-week course. During the first week of instruction, we provide the students with a geotechnical report outline that is consistent with the format used by consultants in practice. To help students meet the due date for the report, we assign benchmark homework assignments. These assignments address important sections of the report and elements of the report preparation process.

We distribute the deadlines for the benchmark assignments throughout the term. Eventually, the students merge their completed assignments into a final report, often with little modification. Table 3 provides the approximate schedule and brief descriptions of the benchmark homework assignments.

Table 3. Benchmark homework assignments

Week*	Assignment	Description
1	Desk Study and Site Visit	Review geotechnical reports and geologic maps for a nearby soil site. Prepare a preliminary soil profile, field exploration plan, and site description.
2	Summarize Applicable Test Methods	Review all ASTM test methods used during the course (about 12 methods). Summarize each method in a brief paragraph; include proper citations.
4	Determine Seismic Site Class	Using results of the field exploration, determine the seismic site classification according to the local building code. Submit calculations and a paragraph describing the procedure and all assumptions.
5	Digitize Boring Logs and Develop Soil Profile	Use a spreadsheet template (provided) to digitize site boring logs. Use boring logs, CPT soundings, and visual-manual soil classifications to create a field exploration plan and final subsurface soil profile.
8	Stress History and Consolidation Parameters	Prepare a table summarizing the results of consolidation tests (e.g., OCR, c_v, C_c, C_r, sample quality, etc.). Prepare a figure of OCR vs. depth. Provide a brief written reflection on the stress history for the site. Include sample calculations and graphical constructions.
9	Interpret Swell Data	Prepare a table summarizing results of all swell tests (i.e., expansion index, swell pressure, dry unit weight, initial saturation, Atterberg limits, etc.). Compare the test results to published values. Provide a brief written reflection on earthwork and grading recommendations for the site.

* - The subject course is taught over a 10-week term.

We modify the objectives for development and improvement of the site with each course offering. For example, students may be asked to plan their geotechnical investigation to support the design and construction of: (1) a warehouse, where shallow foundations are appropriate; (2) a parking structure, where deep foundations and retaining walls are appropriate; or (3) a manufacturing facility, where tolerable settlements are strictly low. Given the time constraints of the quarter and resources available, we cannot conduct a comprehensive site investigation for these projects; only a select number of field explorations are possible. However, defining a project objective provides the students with valuable context regarding the benchmark homework assignments. Students use project information when deciding on exploration recommendations and when analyzing field and laboratory test results.

3.3 Laboratory Testing Schedule and Assignments

We work with the students to design a term-long laboratory testing schedule. The students follow this schedule in generating their own test data and results. These data and results are then incorporated into interpretation assignments, which the students complete as individuals and in laboratory groups. An initial set of laboratory tests are assigned to help the students familiarize themselves with standards and best practices. A final set of laboratory tests are conducted on samples collected during field exploration. The students incorporate the results of these latter tests into their geotechnical engineering report. An outline of a typical laboratory testing schedule is included in Table 4.

For the initial assignments, students perform tests on pottery clay. Performing consolidation and shear tests on this material teaches students how to properly and efficiently perform different test methods. The stakes are lower at this time, before the students test field samples. The following characteristics make pottery clay an ideal introductory testing material: uniformity, homogeneity, readily available, fairly inexpensive, non-sensitive, nearly saturated, and forgiving during test specimen preparation (i.e., handling, carving, trimming, etc.). We purchase the clay in approximately 200- to 300-millimeter blocks from the craft center on campus. The initial consistency is generally "soft" to "medium stiff."

While preparing the pottery clay specimens, the instructor explains and demonstrates mistakes. More common testing errors include poor trimming technique (that leaves a gap between the specimen and the ring wall), disturbing the specimen due to improper handling and/or trimming, not aligning porous stones and end caps, neglecting to measure and/or record important specimen information, not trimming the ends of the specimen perpendicular to the loading axis, not leaving enough capacity in a dial indicator to capture the change in height during an entire test, and neglecting to confirm that instrumentation and/or equipment are in proper working order.

Table 4. Typical laboratory testing schedule

Week*	Assignment	Material Tested	Comments
1	Incremental and Constant Strain Rate Consolidation Testing	Pottery Clay	Begin with long-term tests; use data for supplemental interpretation assignments; train students for eventually working with site samples.
2	Consolidated Undrained Triaxial Shear Testing	Pottery Clay	Teach students to prepare, mount, saturate, and test triaxial specimens.
3,4	Drilling and Sampling	In Situ Soils and Rock	Perform cone penetration tests (CPTs); perform standard penetration tests (SPTs); gather disturbed and undisturbed samples.
5	Prepare laboratory test assignments	----	Confirm sample suitability; assign laboratory tests; prepare a cost estimate of laboratory testing.
6,7,8	Perform Laboratory Tests for Geotechnical Report	Collected Site Samples	Test samples gathered during drilling; students work together to perform the laboratory work small groups.
9	Swell Testing	Collected Site Samples	Perform a variety of swell tests as a class.
10	Report Preparation	----	Complete all laboratory reports and share results.

* - The subject course is taught over a 10-week term.

As a class, students perform six incremental consolidation tests on pottery clay, including pairs of tests at different load increment ratios (LIRs). Students use data collected during the consolidation tests to review different methods for interpreting consolidation test results, evaluate the similarity of results between companion samples, comment on the influence of varying the LIR, and compare coefficient of consolidation (c_v) at different load increments and with different interpretation methods. Students write a brief report addressing whether or not the test results support the conclusions from research papers on relevant subjects (Amundsen et al., 2016; Paniahua et al., 2016; Vipulanandan et al., 2009) and information provided in Holtz et al., (2011). We encourage students to consult this textbook during the subject course. The text is required in prerequisite geotechnical courses.

We use an estimate of the clay's preconsolidation stress from the consolidation tests for interpretation of Stress History and Normalized Soil Engineering Parameters (SHANSEP) during subsequent triaxial shear testing (Ladd and Foote, 1974). In teams of three, students trim and mount four pottery clay specimens for consolidated undrained (CU) triaxial tests with pore-pressure measurements (ASTM, 2011). We consolidate the specimens to known overconsolidation ratios (OCRs) and follow a modified SHANSEP evaluation procedure. We incorporate the results of the CU triaxial tests into a homework assignment on stress paths and interpretation of triaxial data. Students also calculate Skempton's "B" and "A_f" parameters and compare results with published values (Skempton, 1954).

After completing the laboratory pottery clay tests, students perform a field exploration. As noted in Table 4, this exploration occurs over a two-week period. Drilling typically involves hollow-stem auger drilling. We collect soil samples using the standard penetration test (SPT), a Modified California driven split-spoon sampler, and a thin-walled (Shelby) tube sampler. We perform cone penetration tests (CPTs) with pore-water pressure measurements in the vicinity of previously excavated boreholes. We typically perform pore pressure dissipation tests during CPT soundings. Time permitting, we may conduct seismic testing during one of the CPT soundings to measure shear wave velocities for the site soils. The results of the seismic tests help inform the seismic site classification assignment described in Table 3. This table summarizes additional benchmark assignments associated with the field exploration work.

Following field exploration, the students test the disturbed and undisturbed samples that they retrieved and logged (see Figure 2). Table 4 provides the approximate laboratory testing schedule for the latter half of the term. During the fifth week, the students review the condition of the collected samples and prepare a laboratory testing schedule. Testing proceeds during the next three weeks. The bulk of the subsequent laboratory work includes index testing (i.e., Atterberg limits and soil classification), incremental consolidation testing, and triaxial shear testing (i.e., CU and UU). During this time, the instructor will typically perform constant strain rate (CSR) consolidation tests to demonstrate the test method and supplement the student work with additional consolidation test results. Additional benchmark homework assignments associated with this laboratory testing are summarized in Table 3.

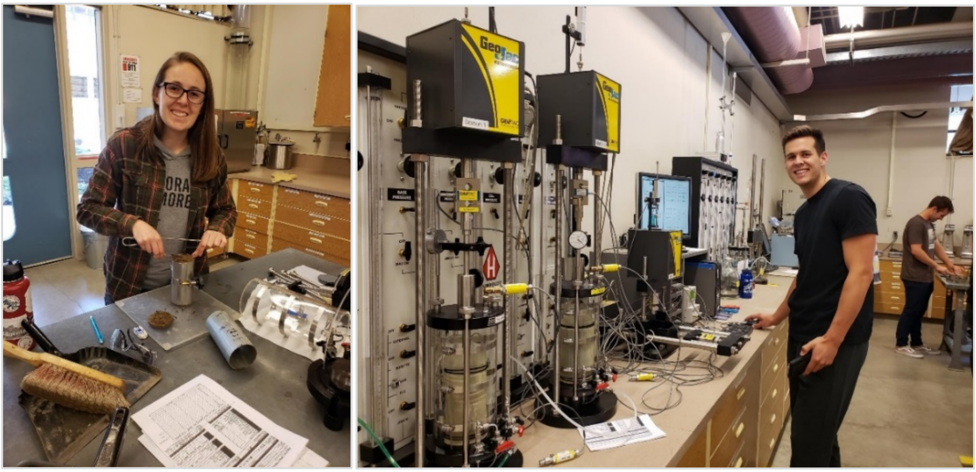

Figure 2. Students in the laboratory testing collected soil samples

As indicated in Table 4, we perform swell tests during week nine. During the lecture portion of the course, we discuss methods to evaluate expansive soil, heave prediction, and mitigation measures. In the laboratory and as a class, we perform an expansion index (EI) test (ASTM, 2019) along with several different methods to evaluate one-dimensional swell pressure (ASTM, 2014). We use our consolidometers and front loading oedometer frames to conduct the latter tests. Students analyze the swell test results as part of a benchmark homework assignment that they later merge into the geotechnical engineering report (see Table 3).

4 Lessons Learned

4.1 Dealing with Mistakes

Mistakes are naturally part of the learning process - they often present a "teachable moment" for the instructor. At times, we have struggled to find a balance between learning from mistakes, providing teachable moments, and generating quality and analyzable data from inexperienced testers. Ultimately, students are tasked with defining a soil profile and selecting characteristic soil parameters for each layer to use in their analyses. Varied data are available including CPT soundings, SPT blow counts, hand torvane and pocket penetrometer results, laboratory mini-vane results, over a dozen triaxial tests results (typical), at least half a dozen consolidation results (typical), dozens of moisture and density results, and at least a dozen classification test results. As a class, we ask the students to collect many soil samples, perform a high number of laboratory tests, and share test results among their project groups. These strategies help us in addressing mistakes. Back-up samples are available for testing and provide opportunities for the students to examine (and re-examine) uncertainties and errors during testing. Sharing results among groups provides increased motivation for the students to be efficient and careful in their testing, as they quickly understand that others are depending on their test results and quality outcomes. Others have commented on the value associated with learning by doing and asking students to share responsibility in their own learning (e.g., Blum, 2016). Being intentional with instructional design in these areas can increase intrinsic motivation and improve student learning.

Additionally, we teach the students to assess consistency among the test data and results when selecting characteristic soil properties for inclusion in their geotechnical reports. For example, an apparently anomalous test result can be compared with CPT data, SPT blow count data, other laboratory results, and published values. Having collected considerable laboratory and field test data affords us this opportunity. As a class, we examine anomalies and discuss likely reasons for misleading results. Identified mistakes often result because of inexperience and provide opportunities to discuss testing errors that may also occur in practice. Typically observed testing errors include: misalignment of porous stones during consolidation testing, forgetting to unlock the loading piston during triaxial testing, improper and/or rough handling of a sample leading to disturbance, incorrect soil classification leading to improper test selection, incorrect sample labels, incorrect calculation and/or assignment of confining loads and stresses, and others. An important intended outcome of the laboratory testing is for students to begin to develop a critical eye when evaluating and relying on test results. Some examples follow.

Our test site consists primarily of clayey soil with some sand layers over bedrock. When performing a SPT within a hollow-stem auger below the groundwater table in a sandy layer, the potential exists for sand to flow into the auger after the center bit is removed and before the sampler is placed back down the hole. In this case, the bottom of the hole is destabilized and disturbed as sand may flow a meter or more into the lead auger. When the SPT sampler is lowered into the auger, it bottoms on the disturbed sand instead of undisturbed soil. "Flowing sand" may be assumed to occupy the bottom of the borehole when the top end of the center rod sticks up above the top end of the augers more than the length of the sampler. Mistaking blow counts in "flowing sand" as accurate could result in an extreme mischaracterization of soil consistency. We use CPT soundings adjacent to borings to illustrate the hazard of not recognizing potentially erroneous blow counts. In one case, at a depth of 9 meters below the ground surface, we observed signs of "flowing sand" prior to performing an SPT. Students noted the potential for erroneous blow counts on their field logs. We subsequently asked students to create a graph of corrected blow count versus depth using SPT and CPT data. The corrected blow count for this test was 25. Data from an adjacent CPT suggested a corrected blow count of 4 for the same depth.

Additionally, various errors may occur when preparing specimens for consolidation testing. Preparation errors are revealed in the data. Figure 3 shows results of four consolidation tests performed at different LIRs on specimens trimmed from the same block of pottery clay. The resulting consolidation curves are consistent, with the exception of Specimen D. This specimen was trimmed slowly and dried slightly before testing. Also, the students used dry filter paper to protect the porous stones - moist paper was used for the other specimens. The initial saturation of Specimen D was 90 percent. Initial saturation levels for the other specimens ranged from 95 to 97 percent. Each specimen was inundated with water after a seating load was applied and then loaded incrementally. As a class, we discussed and identified the preparation mistakes that likely produced the anomalous consolidation curve.

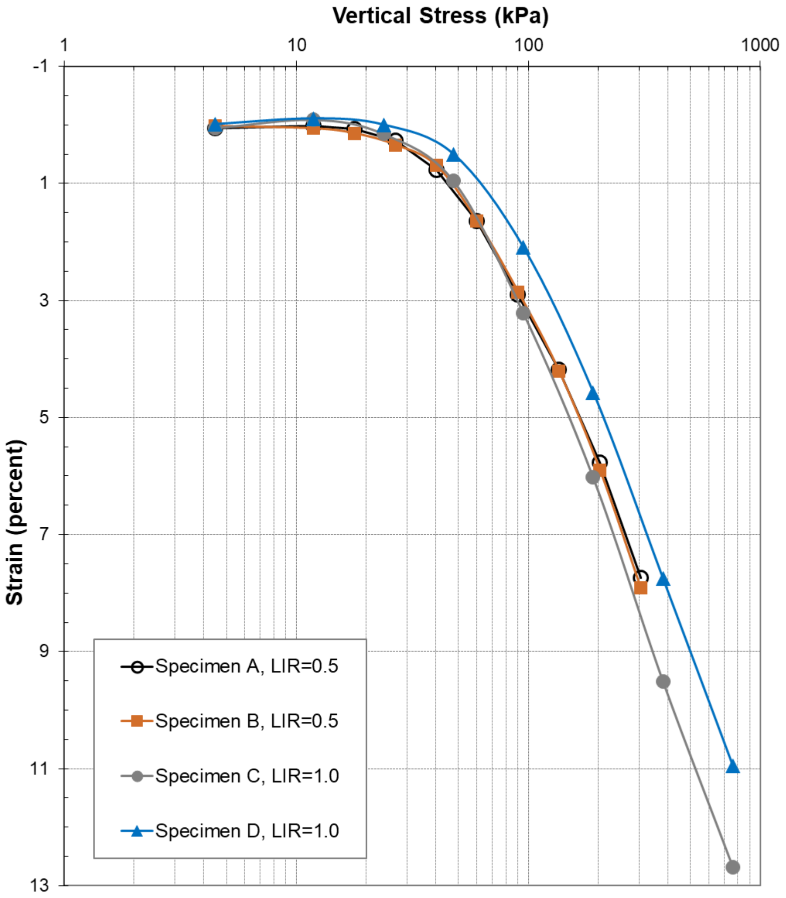

Figure 3. Anomalous results from incremental consolidation tests

4.2 Involving Everyone during Kinesthetic Activities

Typically, most students readily volunteer for hands-on work in the lab and field. However, some students prefer to observe. When students perform kinesthetic learning activities in the laboratory and field they tend to benefit in different ways from the traditional lecture format. Tranquillo (2008) suggests that kinesthetic activities offer the following benefits: (1) produces experiences that enable students to become more invested in the course; (2) allows time for students to make personal interpretations of concepts and connections to other ideas and concepts; (3) provide numerous opportunities for the instructor to check for understanding; and (4) allows instructors to create a rapport with students.

We use several different strategies to encourage all students to participate during the hands-on activities, which include the field exploration and laboratory testing programs. For example, during field exploration, we rotate between groups when processing collected samples. In addition, each student is responsible for creating their own boring log, even though they work in small groups to accomplish the day's tasks. This combination of individual and group responsibility encourages (and requires) open communication as the students share sampling information, drilling observations, and SPT blow counts. After creating the laboratory testing program and schedule, we assign each group a portion of the tests. Each group is given a variety of different tests to perform. To adhere to the compressed schedule and serve a relatively small group, each student needs to participate during all of the hands-on activities.

4.3 Sharing Data Efficiently

Students are charged with compiling all of the test results from testing performed by the entire class for the geotechnical report. Recording and reducing laboratory data consistently and efficiently has been a significant challenge for this course. Laboratory testing sessions are often busy with activity, as students work on a variety of tasks. In the past, we have struggled to have students consistently record all of the required measurements. To help with this challenge, we created spreadsheet-based laboratory worksheets for each of the tests performed. Most of the spreadsheets incorporate embedded figures or graphics to assist the reader in visualizing test results. For index and classification tests, students input their data into the spreadsheet worksheet and e-mail the file to the instructor. After quality assurance checks, the instructor uploads the results to the course website to allow access by all students. The instructor collects and reduces data for tests that require computer data acquisition (incremental consolidation with time rate data, triaxial compression, etc.). Processed results are uploaded as spreadsheet reports to the course website. This routine is consistent with geotechnical engineering practice: a laboratory performs tests and provides reports to the engineer. This process helps ensure the reports are accurate and consistent. Instead of reducing all data and producing reports, which can lead to delays and mistakes, students are free to invest most of their time interpreting and selecting characteristic soil properties. During a course like this, we are careful to not overwhelm the students with more information than they can handle (Kaufman and Schipper, 2018). In addition, we can use the open, accessible, and properly formatted worksheets to address learning outcomes related to data presentation and organization, spreadsheet design and programming, and visual communication.

4.4 Testing Resources

Having enough laboratory resources is another challenge for this class. The bottleneck for equipment access typically occurs with the triaxial cells and consolidation machines. We typically have four teams of students performing a variety of laboratory tests. With six consolidation machines we are able to generate enough data within the compressed testing schedule. We have six triaxial cells for the students to share during shear strength testing, which is adequate. Usually, the students will perform two CU triaxial tests, which commonly take almost two weeks to complete. Each group then has access to one triaxial cell to perform unconsolidated undrained (UU) triaxial tests. We have three load frames available for triaxial testing. The load frame packages we selected are computer-controlled with automatic data acquisition. The software package is flexible enough to perform non-routine research testing but is also intuitive for student use. During testing, the software provides a realistic visual schematic of the test setup with live readings for all sensors. We can use the software to generate real-time plots of data in seconds. We train students to operate the load frames and software during one laboratory testing session. Although we operated and maintained our own field drilling and testing equipment in the past, we now collaborate with local geotechnical contractors who complete the field exploration work in kind. The time and effort we have devoted to developing these partnerships has been well spent.

4.5 Assessment Efforts

We incorporate formative and summative assessment efforts during the course. Our formative efforts involve observation and mentoring of the students during testing as well as review of the benchmark assignments. We use these assignments to monitor student progress, provide positive feedback, offer guidance on errors and mistakes, and identify gaps in knowledge and understanding. If learning gaps are identified, we have time to schedule supplemental discussions and/or lessons prior to submission of final project reports. Summative assessment efforts involve primarily student evaluations of teaching and final report evaluations. Recent student evaluations have been overwhelmingly positive, which is expected to a certain extent, given the regular improvements and refinements made to the course over time, the small class size, the opportunities for one-on-one instruction, and the hands-on nature of the learning experience. In addition, the final reports have been consistently well written, organized, and presented. We use a scoring rubric when evaluating the final reports. We present the rubric to the students at the beginning of the term and intentionally link the rubric with key aspects of the geotechnical engineering report. Essential elements of the scoring rubric are outlined in Table 5.

Table 5. Geotechnical Engineering Report Scoring Rubric

Scoring Element	Percentage	Comments
Material Property Evaluation	25	Interpretation of field and laboratory test results, supporting analyses, presentation of results
Conclusions and Recommendations	30	Written summary of findings, foundation type selection and recommendations, construction considerations, supporting calculations
Site Conditions	20	Technical descriptions of work performed and findings, subsurface cross-section(s), field and laboratory data appendices
Presentation and Organization	5	Creation of a portfolio quality document
Clarity of Writing and Documentation	20	Tables, figures, technical writing, sources cited, reference section

5 Conclusions

In this paper we discussed the development and implementation of a project-based geotechnical field and laboratory testing course. Based on our success, we encourage other educators to consider similar learning outcomes and project-based learning activities in their own courses. We are happy to share our course materials and additional project details directly with others.

Through our experiences teaching and assessing this course, we have learned a lot about our students. These students often experience challenges when working in groups; need to improve their information literacy skills; require regular and constructive feedback; find the subject of geotechnical engineering interesting, relevant, and challenging; relate well to the subject matter when it is linked with contemporary and/or practice-oriented issues; require support and direction when asked to self-direct their learning; and appreciate hands-on demonstrations and project-based learning. Additionally, interaction with our students during field and laboratory activities (e.g., listening to their comments, observing their actions, addressing their questions, etc.) provides opportunities for knowledge checks that lecture formats do not easily accommodate. We reflected on these observations and a number of "lessons learned" as we revised and improved the course curriculum.

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Authors’ bios

Nephi Derbidge, California Polytechnic State University (Cal Poly), USA

Nephi Derbidge is a Lecturer and Instructional Support Technician at Cal Poly, San Luis Obispo. He worked as a geotechnical engineering consultant in California for over 15 years before transitioning to teaching and academia. He earned a degree in Civil Engineering in 1997 and a California Teaching Credential (Mathematics) in 2003. Nephi has extensive geotechnical engineering project experience related to highway improvements and bridges, commercial developments, nearshore structures, slope reconstructions, and public works facilities. In addition, he has served as construction services and laboratory manager. As laboratory manager, he was responsible for sophisticated and routine geotechnical testing services for numerous geotechnical offices in California. In his current role, Nephi holds a dual appointment: (1) serving as an instructional support technician for Cal Poly's geotechnical, materials, structures, and pavement laboratories; and (2) teaching geotechnical and materials engineering courses.

Gregg Fiegel, California Polytechnic State University (Cal Poly), USA

Gregg Fiegel is a Professor of Civil Engineering and serves as Director of the University Honors Program. He began work at Cal Poly in 1995 after earning Ph.D. and M.S. degrees from the University of California, Davis. He is a Cal Poly alumnus as well as a registered Professional Engineer (P.E.) and Geotechnical Engineer (G.E.) in California. As an instructor in Civil Engineering, Gregg has taught numerous undergraduate and graduate geotechnical engineering courses. In addition, he co-led the initial design and implementation of the yearlong Civil Engineering Senior Design course. Gregg has extensive experience advising and teaching first-year students in Civil Engineering and Honors. The latter is an interdisciplinary program serving over 450 students from all 6 of Cal Poly's colleges and nearly 60 different majors. In Honors, he developed and now co-teaches a three-quarter, first-year experience focused on sustainability, environmental justice, project-based learning, leadership, and service.

A Project Based Assessment of the Foundation Engineering Course for Large Class Sizes

G.C. Fanourakis

University of Johannesburg, South Africa
georgef@uj.ac.za

ABSTRACT: The Engineering Council of South Africa has a mandatory requirement that all the courses of the Baccalaureus Technologiae degree shall comprise a project. The passing of this project is required in order to pass the course. The purpose of such projects is to assess whether a student has understood the knowledge imparted and is able to appropriately apply it. Allocation of a different project to each learner in the case of large class sizes poses a practical problem. Hence, group projects are opted for. Furthermore, the fair evaluation of the group projects and allocation of specific marks to each member based on actual contribution poses a challenge, as it is not acceptable to allocate the same mark to every group member. This paper proposes an original comprehensive system for, firstly, assessing the application of knowledge and secondly, fairly assessing group projects and allocating specific marks to the individual members. This system was implemented in the Foundation Engineering IV course, at the University of Johannesburg. The system was successful as 91 % of the learners achieved the outcomes. In addition, the individually allocated marks appeared fair as none of them were queried.

Keywords: Engineering, Geotechnical, Assessment, Projects

1 Introduction

The Engineering Council of South Africa (ECSA), which accredits academic qualifications for the purposes of professional registration, has imposed a mandatory requirement that all courses of the Baccalaureas Technologiae: Civil Engineering degree should comprise a project. Project-based Learning (PBL) is an effective practice (Powell, 2004; Jackson et al., 2012). The objective of such projects is to assess the appropriate application of the course content taught. Furthermore, this project component contributes a minimum of 30 % towards the course final mark. Failure of the project (a mark less than 50 %) results in failure of the course, irrespective of the marks obtained in the other assessments.

Allocation of a different project to each learner in the case of large class sizes (comprising approximately 150 learners) poses a practical problem, as there are not enough topics to allocate a significantly different topic to each student. This problem is exacerbated by the fact that new topics need to be introduced every year that the subject is offered, to avoid possible copying of previous projects. In addition, the marking of a large number of projects by the lecturer, which is mandatory (i.e. no marking assistance is permitted), would not be possible in the timeframe available.

Furthermore, if group projects (instead of individual projects) are opted for, the fair evaluation of the group projects and allocation of specific marks to each member is a challenge, as it is not acceptable to allocate the same mark to each group member. Hence, a system is required that fairly assesses each member's contribution.

The purpose of this paper is to propose original comprehensive systems for, firstly, assessing the application of knowledge and secondly, fairly assessing group projects and allocating specific marks to the individual members. These systems were implemented in the Foundation Engineering IV course, at the University of Johannesburg.

2 Literature review

2.1 Project assessment

Geotechnical Engineering courses (including Foundation Engineering) are generally assessed by means of one or more of the following methods: tests, assignments, examinations, laboratory reports, designs or other type of projects. Gratchev & Jeng (2018) conducted research considering soil mechanics students over a 3-year period, where they gave students the option to choose between project-based and traditional assignments. Their research concluded that, although the marks obtained by the project-based and traditional assignment student groups were similar, students who selected the project-based assignment reported higher engagement with the learning process. Kunberger (2013), who converted a Geotechnical Engineering course from a lecture to a project-based approach, also reported that students gave positive comments and that their performance met the stated objectives.

Scoring guides for marking of the projects are specifically compiled, depending on the nature of the project. Hence, such scoring guides are not standardised.

2.2 Member specific mark allocation

Peer review systems may be used as a sole or partial basis for allocating project marks to group members.

A number of researchers have relied on peer evaluation methods to allocate marks to individuals in a group, including Rafiq & Fullerton (1996), Baker (2008), Wang & Vollstedt (2014) and Van Hattum-Janssen & Lourenço (2006).

Triantafyllou & Timcenko (2014) provide a literature review of project-based peer assessment systems, applicable to engineering group projects.

Peer review systems have been deemed not ideal, as the students are too inexperienced to evaluate their peers (Jassawalla et al., 2009). Furthermore, these methods do not evaluate specific skills and do not render feedback to the students (Saavedra & Kwun, 1993). In addition, the peer assessment system is also characterised by inevitable bias introduced by students during the assessment process (Li, 2001).

Others have devised assessment systems that are based on peer assessment as well as assessment by the instructor, either by assessing individuals (Wengrowicz et al., 2017) or by assessing the project report and presentation (Hersam et al., 2004).

Wang and Vollstedt (2014) developed an automated method. This method calculates a mark for the individual by considering the performance of the individual relative to the other group members in other individual assessments. It assumes that a student who performs better in individual assessments should obtain a relatively higher mark for the group project. The authors of this model did not recommend its global implementation, but rather that it be used to flag anomalous cases.

The above methods do not rely on the sole expertise of the course presenter to mark the report and allocate marks to individuals based on their involvement. Hence, a new method for allocating individual marks from a group project is proposed below.

3 Details of the Foundation Engineering IV course

3.1 General

The Baccalaureus Technologiae: Civil Engineering degree is offered, by a number of national universities in South Africa, in a number of specialist fields including structures, transportation, water and management. The field of specialisation is based on the majority of the subjects selected. At the University of Johannesburg, the Foundation Engineering IV course is compulsory for all the specialist fields.

The lectures for this course amount to approximately 40 hours, presented as a series of three-hour weekly lectures, over a semester.

3.2 Course syllabus

The course syllabus comprises of the following main sections.

- Site investigations: Stages of investigation, SAICE (2010) Site Investigation Code of Practice, GFSH-2 (2002): Geotechnical Site Investigations for Housing Development, field tests and laboratory tests.
- Bearing Capacity: Including theories and methods.
- Settlement: Theory, classical and elasticity based methods of prediction.
- NHBRC (2014) Manual: (including residential site classification) and heave prediction methods.
- Piling: Types and application, capacity (including uplift and lateral loads), settlement and pile groups.

Successful completion of this module should equip the learner with the fundamentals, including theory, methods of analysis and knowledge of laboratory tests to apply scientific principles and the engineering judgment required to design a foundation or foundation system.

3.3 Assessment

This module is run on a continuous assessment basis. Hence there is no final examination.

The course is assessed by two open book tests and a project. The project counts 30 % towards the final mark. A minimum of 50 % is required to pass the project. In addition, passing the project is a requirement to passing the course. In accordance with ECSA's requirements, at least one of the tests has to be moderated externally (by an industry-based expert).

The Moderator is sourced and appointed by the course instructor. In the case of at least one test, the question paper has to be moderated (prior to it being written) and at least 20% of the total number of scripts (139 registered students in 2019) have to be reviewed. The scripts to be moderated have to be selected from top-performing, average-performing and low-performing students and have to be signed by the Moderator. The Moderator is also available to assist in any other relevant way (e.g. cases of dishonesty). The project is also discussed with the Moderator before being detailed in the study guide. In this course, the projects were also discussed with the Moderator after being marked. Generally, the best, average and fail projects are reviewed by the Moderator, devoting more attention to the projects that failed, as failing the project means failing the course. In this course, the Moderator spends approximately 15 hours (in a semester) on the above tasks. Moderators are remunerated at a nominal rate, however, they undertake this appointment primarily for the purpose of giving back to the profession. Often Moderators refuse to be remunerated. Incidentally, they may record the hours spent as Continuous Professional Development (CPD), which is required for renewal of professional registration.

4 Project details

4.1 General

According to ECSA, projects should involve the "solution of real/industrial/applied problems using fundamental principles that underpin current technology".

At the first lecture students were given the opportunity to place their names in a group. A total of 23 groups, each comprising of six members, were formed.

4.2 Brief

In 2019, each group was randomly allocated a different typical soil profile (and its geographical location), from a different region in South Africa. The allocation of the different profiles was done on a random basis. These profiles were taken from reports of various geotechnical investigations, in which the author of this paper was involved.

An example of a relatively complex soil profile, allocated to one of the groups, is shown in Figure 1.

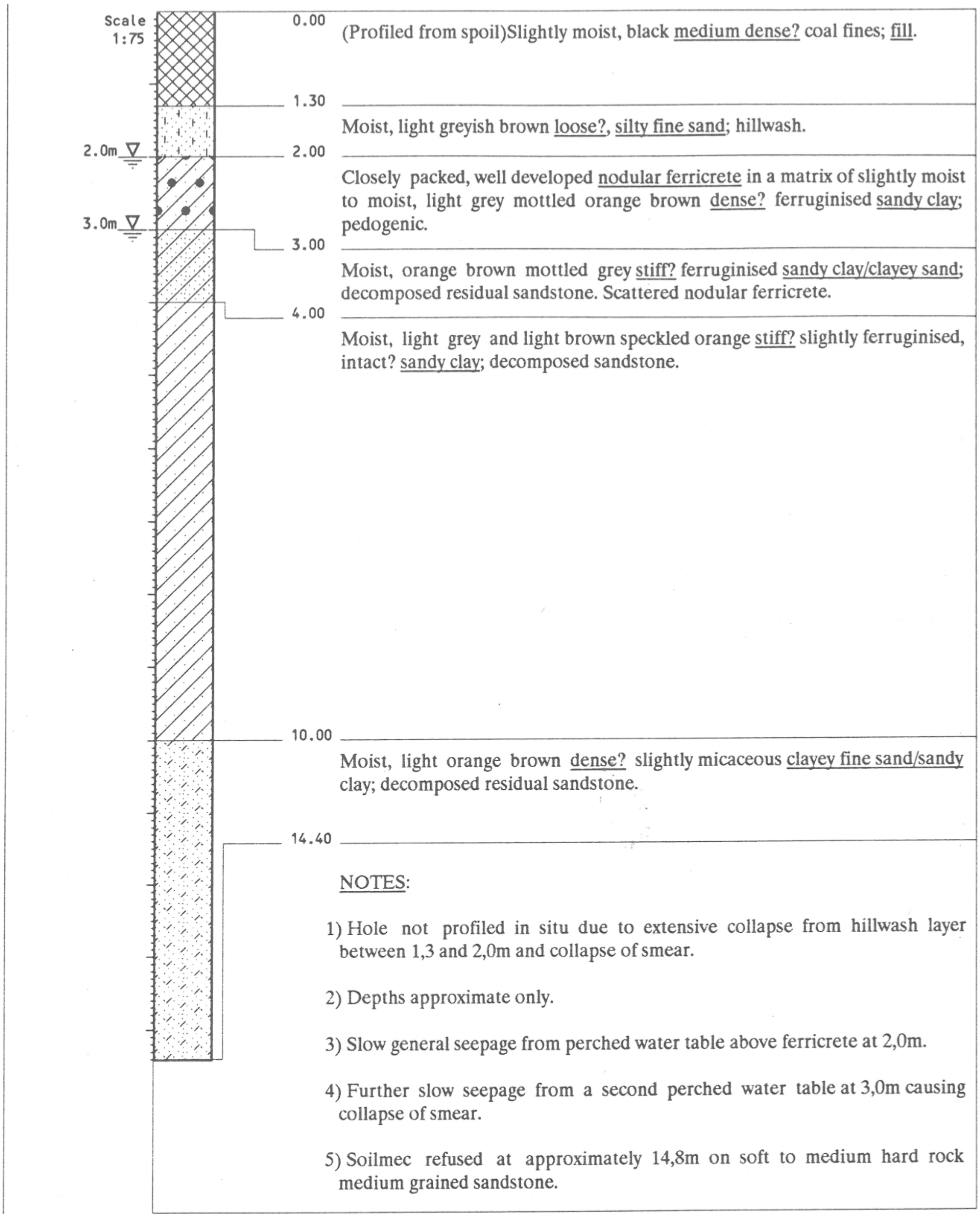

Figure 1. Example of a relatively complex soil profile

In the soil profile in Figure 1, question marks appear alongside the consistencies of the layers below 1.3 m. The reason for this is that the consistencies of these layers were determined from the excavated soil and not in the usual manner (using a geological pick when in the hole) as, due to extensive collapse, it was not safe to descend into the hole. However, in this case the students were requested to regard the questionable consistencies as being actual.

The 23 soil profiles varied in complexity and were taken from reports of investigations which were conducted in three of the nine National Provinces of South Africa, namely Gauteng, Free State and Mpumalanga.

All the projects were based on geotechnical aspects for a single-storey housing development.

Each group was given a different area size for their housing development site. These areas, for the various groups, ranged from 2 to 500 hectares.

On the basis of the soil profile and area size allocated, each group was requested to prepare a report.

The report was to comprise the following four aspects.

- Details of the geotechnical investigation that should be conducted for the housing development. This should include, but not necessarily be limited to, details of the fieldwork (e.g. type and number of test pits and type and number of field and/ or laboratory tests).
- For the profile allocated, reasonable horizon properties should be assumed (and their source justified) for the appropriate tests that would have been conducted in an actual investigation.
- Using the reasonable horizon properties (above), a relevant analysis, should be conducted. This analytical component of the report should include evidence of the application of knowledge acquired during this Foundation Engineering course and prior Geotechnical Engineering courses. Therefore, the analytical component of the report should include calculations of bearing capacity, settlement and heave etc. (where applicable).
- On the basis of the analysis, the Site Class and relevant founding options for the housing development should be recommended.

Reports should be typed and well presented. A lengthy final report is not expected (maximum 5 pages excluding appendices). The report should explain each group's project, the background and theory if relevant, summarise the findings of the group's work and include some discussion/interpretation of the results. Submission of reports by individuals who preferred to work on their own was not an option.

The projects for the following years will be different from the 2019 project, by changing the following details:

- The nature of the proposed development. In 2019, the project was based on a single-storey housing development. This could be amended to a very different development, for example a multi-storey office building.
- Soil profiles allocated to groups. The author is in possession of hundreds of soil profiles, from over 70 geotechnical site investigations, that may be used.

4.3 Assessment

4.3.1 Report Assessment

The assessment of the technical content of the group report was done in accordance with a scoring guide, which considered seven main criteria, shown in Figure 2.

The marking was conducted by the course presenter (author of this paper) and was not based on any form of peer review system.

Description of Criteria	Maximum Marks	Mark Obtained	Comments
Understanding of Project Objectives and Structure of the Report	10		
Investigation Details and Relevance	20		
Assumed Properties and their Justification	10		
Analysis and Application of Knowledge *(Including calculations e.g. bearing capacity, settlement and heave).*	20		
Discussion and Recommendations	15		
Initiative, Creativity and Originality	10		
Presentation	15		
TOTAL =			**100**

Figure 2. Report marking scoring guide

4.3.2 Allocation of specific marks to group members

The introduction to the report included a paragraph stating which part of the report each group member was responsible for. It was not acceptable to state that all members were responsible for all parts of the report. In addition, the Agreed Group Relative Contribution Assessment Sheet shown in Table 1 was included in the report. The purpose of this sheet was to appropriately allocate marks to each group member based on their individual contribution and the project report mark.

Before filling in the sheet below each student was requested to conduct a self-assessment, by giving themselves a mark out of 10 for each of the four categories. Thereafter, the group was to meet and on the basis of the self-assessments, discuss and agree on each person's mark for each category. Although, thus far, this system includes elements of peer review, it differs from peer review systems in that the score of each individual had to also be agreed upon by the individual being rated.

Table 1. Agreed group relative contribution assessment sheet: a sample[1]

Activity	Group Member Name or Initials					
	A	B	C	D	E	F
Attendance of Meetings (max 10)	10	10	10	10	10	10
Intellectual Contribution (max 10)	10	8	7	10	9	7
Research and Analysis (max 10)	10	8	9	9	9	8
Report Compilation (max 10)	10	9	7	8	8	7
Total	40	35	33	37	36	32

[1] scores correspond to the group that earned the highest report mark (96 %)

The mark of each group member was calculated by multiplying the project mark by the ratio of each group member's score to the maximum score obtained by any member. Hence, for example, as the maximum score obtained was 40, the project mark allocated to, for example, Member "C" was 33/40 x 96 % = 79 %.

In certain cases, the mark calculated for each student was further adjusted by considering both the explanation given in the introduction (regarding which member was responsible for the various components of the report) and the marks awarded for the seven criteria in the marking scoring guide (Figure 2). Such rare adjustments were generally made in the case of members who were responsible for a task associated with a criterion in the scoring guide that obtained an excellent or a poor mark.

The proposed system awards individual marks based on both effort and content produced.

The projects were viewed by and discussed with the Moderator, before being released to the students.

5 Discussion

5.1 Group report results

Figures 3 and 4 show the marks pertaining to the seven criteria constituting the marking guide for the reports that obtained the highest (best), average and lowest (worst) marks which were 96 %, 60 % and 32 %, respectively. Only two of the groups failed the report and consequently failed the course.

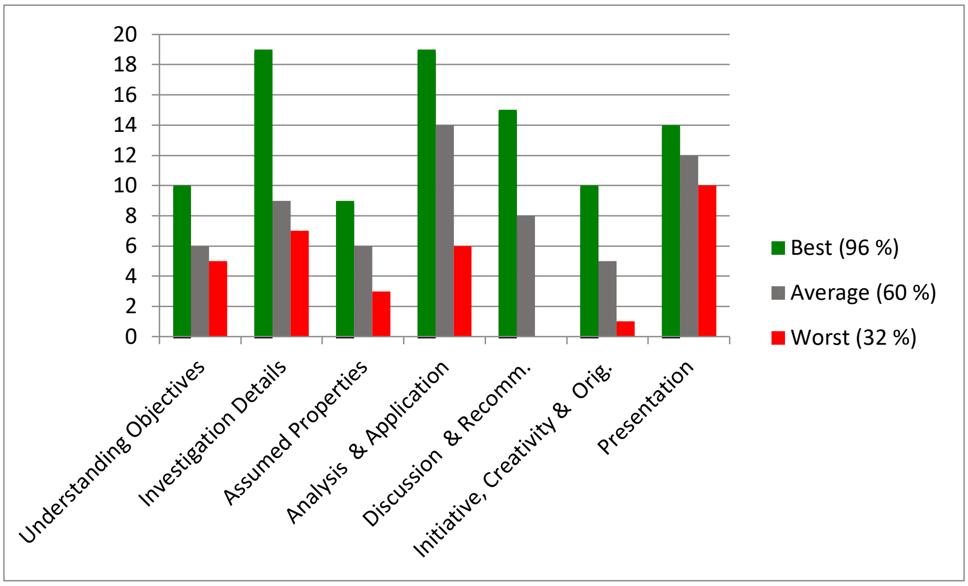

Figure 3. Marks obtained for specific assessment criteria of reports

The best and worst reports are briefly discussed in Sections 5.1.1 and 5.1.2.

5.1.1 Best report

The best report was excellently written, earning a mark of 96 %, for the following reasons.

- The introduction included a detailed table specifically indicating which group member or members were responsible for compiling the various aspects of the report.
- The report was very well structured, like a typical geotechnical investigation report, and included sections briefly describing the site topography, geology, hydrology, seismic considerations, vegetation, details on the typical soil profile characterising the site, the location of the testpits and details on the site investigation.

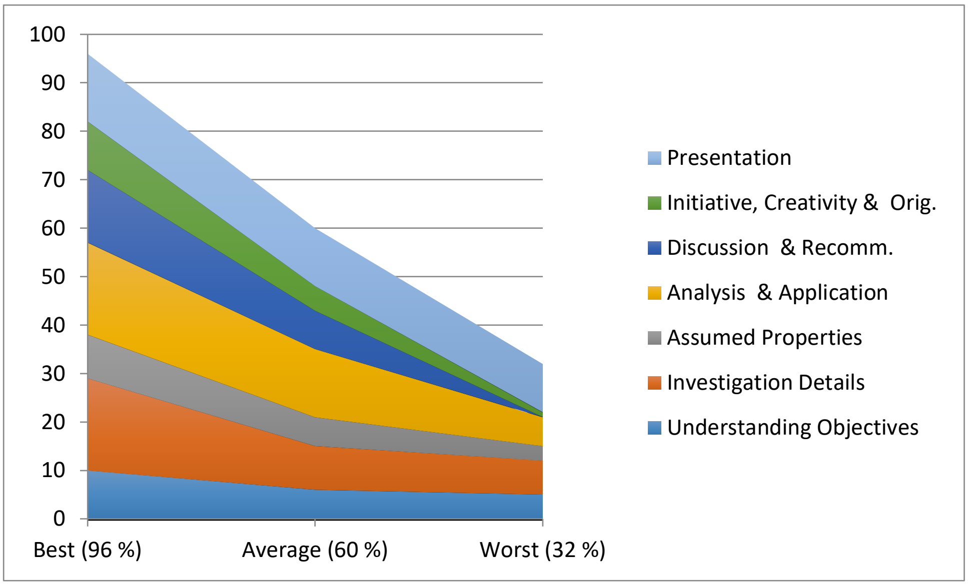

Figure 4. Cumulative marks obtained for specific assessment criteria of reports

- The number of testpits and data points collected were in compliance with the SAICE (2010) Site Investigation Code of Practice and GFSH-2 (2002) Specification, for the area size assigned to the group.
- The site investigation included field and laboratory tests or requirements that were relevant to the soil profile allocated to the group. For example, trenches were excavated (rather than deep auger holes), as the soil depth to be investigated (including profiling) was approximately only 3m deep. In addition, with regards to laboratory tests, an undisturbed sample was taken from each layer for the determination of its grading, Atterberg limits and consolidation properties.
- The properties assumed for the tests for the soil horizons were appropriate and reasonable and their source justified, including from previous reports and a journal publication. For example, Elastic Modulus values (from a report) and e vs log pressure relationships (from a journal publication) were assumed to be applicable to the soil profile and hence were used to estimate the settlement.
- The potential problems associated with the different layers were identified (in this case, heave, settlement and bearing capacity).
- The calculations for heave, settlement and bearing capacity were appropriate and correct.
- Spreadsheets were set up for calculating allowable bearing capacity (according to Meyerhof's method) and settlement.
- The Residential Site Class Designation and associated founding recommendations (according to the NHBRC Manual) were correct.
- The group used Google Maps to ascertain the topography and land usage of the area.
- The report was concise, being only 5 pages (excluding the appendices).
- The references were sufficient.

This report indicated that the group understood the objectives of the project. In addition, it was clear that the work covered during the lectures in the various sections including site investigation, bearing capacity, settlement, heave, site classification was well understood and appropriately applied for the development type (single-storey housing), soil profile and area size allocated to the group.

5.1.2 Worst report

This report was unacceptable and obtained a mark of 23 %, for reasons that include the following.

- The report appeared to be essentially plagiarised from another geotechnical engineering report which was written for a power station (not a housing development).
- The geology did not correspond with that indicated on the allocated soil profile.
- The minimum site investigation data points specified were excessively incorrect.
- Incorrect layer depths were used in the calculations.
- Bearing capacity, heave and settlement calculations were incorrect.
- The Residential Site Class Designation was incorrect.
- The foundation recommendations were not even relevant to the soil profile allocated to the group. As is evident from Figures 3 and 4, a zero was obtained for the discussion and recommendation aspect of the report.
- The report addressed matters not relating to the housing development.

This report indicated that the objective of the project was not achieved. Furthermore, at no stage did any members of this group utilise the scheduled consultation opportunities, which were available throughout the semester.

5.2 Comments

Challenges included a conflict that arose between a group member and the group co-ordinator. This arose as the co-ordinator apparently excluded the member from meetings. The problem was resolved by meeting with both parties.

In addition to the group members of the abovementioned (worst) report, another group failed with a mark of 42 %. The general reasons for this report not meeting the outcomes were as follows.

- The site investigation details were incorrect as they did not comply with the relevant national manuals.
- Bearing capacity calculations were not carried out.
- Incorrect assessment of potential soil problems associated with the allocated soil profile.
- Contradictory inadequate founding recommendations.
- Poor report structure (including the absence of sections and appendices referred to in the report).
- Evidence of plagiarism.

A different problem arose in that one person did not work with their group and submitted an apparently plagiarised report on their own. This report was not marked. In addition, in accordance with the study guide, individual submissions were precluded.

6 Conclusions

In accordance with ECSA's requirements, the objective of the group project of Foundation Engineering IV was the solution of "real/industrial/applied problems using fundamental principles that underpin current technology". In this case, the appropriate application of the Foundation Engineering IV course content to a housing project development was required. It was clear that the outcomes of the group project were achieved by 21 of the 23 groups. As such the pass rate was 91 %.

Both reports that obtained failure marks contained evidence of plagiarism. Hence, it appears that the reason why these two groups failed is due to obtaining other geotechnical reports with the aim of adapting their contents to suit the scope of the course project. This precluded the achievement of the outcomes of the course project that necessitated the appropriate application of the subject matter in a simulated situation.

A method was established to fairly allocate a mark to each group member. This method appears fair and successful, as there were no students who were dissatisfied with their project mark or the mark awarded to other group members. Finally, this method was approved by the course Moderator.

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Author's bio

George C. Fanourakis, University of Johannesburg, South Africa

Professor George C. Fanourakis joined the Department of Civil Engineering Technology at the (now) University of Johannesburg (UJ) over twenty-six years ago, after leaving his employment at Jones and Wagener (Pty) Consulting Engineers. He received the degrees MSc(Eng) from the University of the Witwatersrand and a DTech(Eng) from the UJ. He is a Chartered Civil Engineer and Fellow of the Institution of Civil Engineers (UK). He is a Fellow of the South African Institution of Civil Engineering, Honorary Fellow and Past President of the Institute of Professional Engineering Technologists, Member of the Soil Science Society of Southern Africa and Member of the fib (Fédération Internationale du Béton). His professional involvement includes serving on three Geotechnical National Standards (SABS) Committees as well as Membership of Commission 9: Dissemination of Knowledge, of the fib. His primary general teaching and research interest areas are Geotechnical Engineering and Concrete Technology. In addition, Prof. Fanourakis is active in research in engineering education.

In Search of Approaches to Embed Teaching of Geosynthetics within the Curriculum: Filling an Educational Gap

M. Ferentinou & Z. Simpson

University of Johannesburg, Johannesburg, South Africa
mferentinou@uj.ac.za, zsimpson@uj.ac.za

ABSTRACT: In this paper, we present lessons learned from the application of a set of activities aimed at introducing knowledge about geosynthetics within the existing curriculum of a geotechnical engineering course at a South African university. We explain how students were exposed to the multiple functions and benefits of geosynthetics, through a combined approach of selected readings, problem solving activities, physical models for class demonstrations, a guest lecture by an invited industry professional, and a group assignment. The students' experiences of this program were evaluated using a qualitative survey instrument.

Keywords: geotechnical engineering education, geosynthetics, student engagement

1 Introduction

Geosynthetics is among the most important innovations in geotechnical engineering in the second half of the 20th century (Giroud, 2006). These products have become pervasive in geotechnical engineering, to the extent that it is scarcely possible to practice geotechnical engineering without the use of geosynthetics. Geosynthetics play a role in mitigating many of the global crises facing society today, by improving water quality, protecting the environment, recovering from natural disasters, providing economically-viable solutions, and supporting a sustainable future.

The use of geosynthetics is even more vital in Africa, which is affected by climate change in the form of long periods of drought and more frequent extreme weather events. Expansive lateritic soils, collapsible soils and dolomitic ground leading to sinkhole formation are just a few of the geotechnical problems that can be treated effectively using geosynthetics. In addition, extensive mining activity, and support of road, railroad and bridge networks necessitate more regular use of geosynthetics in the design of geo-engineered structures. A geosynthetic solution provides more guarantees for a sustainable future, particularly regarding water transport systems, preservation of the quality of fresh water, erosion control, crop protection and urban agriculture.

In this paper, we present and investigate an approach to introducing geosynthetic engineering into a geotechnical engineering course in a South African university. We explain how students were exposed to the multiple functions and benefits of geosynthetics, selected readings, group assignments, problem solving activities, physical models for class demonstrations, and a guest lecture by an invited industry professional and a group assignment. We evaluate these activities by using a qualitative survey instrument. The remainder of this paper is structured such that it begins with an overview of the importance of geosynthetics in geotechnical engineering design, and therefore, of incorporating geosynthetics into the geotechnical engineering curriculum. Thereafter, the methodology deployed is discussed in greater detail before the results of this research are presented and conclusions and recommendations are made.

2 Importance of geosynthetic solutions

A geosynthetic is defined, in the international standard EN ISO 10318 (AFNOR, 2015), as a product where at least one of the components is made from synthetic or natural polymer, in the form of a sheet, a strip, or a 3 dimensional structure, used in contact with soil and/or other materials in geotechnical and geo-environmental applications. Geosynthetics, in various forms, have been used successfully for around 50 years in various applications such as reinforced earth walls, ground improvement, slope protection and stabilisation, sanitary landfill, roads and airport runways, as well as tunnelling. More recently, their use has evolved considerably with the development of new materials and their use is now widespread in geotechnical engineering practice. In Table 1 key functions along with main applications and impacts of geosynthetics are grouped.

Table 1. Summary of functions and applications of geosynthetics

Functions	Applications	Mitigation effect
Barrier	Dams, canals, reservoirs / pipelines	Minimise contamination of municipal solid waste and tailings storage Prevent water infiltration to underground aquifer and gas mitigation from the atmosphere
Drainage	Roadway embankments Pavement edge drains, slope interceptor drain, abutment and retaining walls drains	Pore water pressure dissipation / earth structure stability
Filtration	Drainage aggregate / pipes	Soil migration
Reinforcement	Reinforced soil walls, rod and railways, landfills, or bridging sinkholes Reinforced Embankments	Failure, earthquake loading, settlement and settlement differences
Separation		Surface runoff
Surface Erosion control	Coastal lines	High waves, high tides, multiple storm events

Because of their high strength and durability, geosynthetic technologies are broadly used to mitigate the effects of natural disasters and protect against the impact of climate change. Examples include reinforced embankments that resist overtopping induced by tsunamis and river flooding, and reinforced soil walls and/or geo-nets for rock fall protection.

Despite all of these benefits and applications, the International Geosynthetics Society (IGS) (2019) indicates that graduating engineering students often have little or no exposure to appropriate use of geosynthetics in engineering practice. In North America, for example, only 45 university engineering programmes include geosynthetics education in their curricula. As such, a major goal of the IGS Council is to ensure that “geosynthetics become indispensable to the point that they are regularly included in engineering curricula and relevant design standards”. Moreover, a specific objective has been to “introduce geosynthetic education at the undergraduate level”.

Some programmes introduce geosynthetics by way of a 14-week-long module on “Geosynthetics in Geotechnical Engineering”, offered at Master’s level, for example in the USA, Portugal, France, India (Gabr, 2019; Pinho-Lopes, 2018). In South Africa, “Geosynthetics Engineering” is one of the elective modules offered in a coursework Master’s program specialising in geotechnical engineering offered by the University of Cape Town. The current practice in a majority of South African universities, at undergraduate level, is to invite guest lecturers to present case studies and products to third or final year students. We argue that this model can prove to be less effective, as students are often overwhelmed by the plethora of products and materials, thus failing to focus on and understand the basic functions and benefits of geosynthetics. In this paper, we seek out methods to introduce a structured, formative and student-centred approach to introducing geosynthetic engineering to undergraduate students. The rationale is to develop a curriculum where more emphasis is given to geosynthetic engineering, since graduate skill needs to be aligned with current engineering practice and needs.

3 Methodology

The Civil Engineering programme under study in this paper is a four-year programme, consisting of eight semesters, and includes an overall credit value of 604 credits with the requirement of successful completion of 46 modules. The first two years of the programme primarily include introductory modules that present the foundations of mathematics, the natural sciences, and engineering science. The third year of the programme includes core engineering science modules across several specialist areas, such as structural engineering, geotechnical engineering, transportation engineering, hydraulic engineering and environmental engineering. Geotechnical engineering education includes two semesters of Geotechnical Engineering at 3rd year level and one semester in Foundation Engineering at 4th year level. Basic elements of project management are also introduced in the third year. The first semester of the fourth year develops the aforementioned specialist areas as well as project management, while the second semester of the final year is almost entirely devoted to two capstone courses in research investigation and engineering design. The current structure of the program does not include electives.

The purpose of this research was to develop and investigate a pedagogical process aimed at exposing students to the value of geosynthetics in geotechnical engineering practice. This pedagogical process was conducted over a number of weeks during the third-year modules in geotechnical engineering. It entailed a combination of problem solving, a guest lecture on the use of geosynthetics in geotechnical engineering practice presented by an industry colleague, and selected reading from the literature. The guest lecturer presented case studies on slope stabilisation, basal reinforcement, applications in pavement engineering, and construction of high walls in urban and mining environments. Students observed a practical lecture demonstration on calculation of slope stability – with and without reinforcement and they were asked to solve a relevant problem as a small, in-class assignment. Later, students were required to complete a survey pertaining to their perceptions of and attitudes towards the applications of geosynthetics in geotechnical engineering.

3.1 Student engagement in class activity involving geosynthetics

A classic example from the 8th edition of Craig's Soil Mechanics (Knappett & Craig, 2012) was used in order to illustrate the effective use of geosynthetics in accelerating the rate of consolidation. Another problem was given to demonstrate the effect of geosynthetics on increasing the slope stability factor of a fill embankment. This was done as per the recommendation of Stark (2018), made during the Educate the Educators programme offered by the IGS & Geosynthetics Interest Group of South Africa (GIGSA) in July 2018, namely, that it is advisable to incorporate geosynthetics in existing lectures rather than creating standalone lectures on geosynthetics. In this way, students may be exposed to a range of diverse applications.

The first selected application pertained to the drainage function. The students had been taught about consolidation for almost four weeks and were also shown a video on the application of prefabricated vertical drains. The students were given a problem from Craig's Soil Mechanics (example 4.7 on p. 139) which required them to calculate the settlement of fine-grained soil due to consolidation and to show how the consolidation is accelerated through the use of prefabricated vertical drains.

First, the students needed to calculate the final settlement of the clay layer under the large fill. They then needed to compute the settlement after 3 years, and the required time for 95% of the consolidation to occur (which was found to be 9 years). Thereafter, the students had to determine the spacing of 100mm diameter sand drains in order to ensure that all but 25mm of consolidation settlement would occur within 6 months of placement of the embankment. The correct answer for the final settlement was found to be 2.4m. Finally, the students had to repeat the calculations using a square pattern of 400mm diameter sand drains to find that the spacing would increase to 3.2m.

The second selected application was a problem where the students had to consider a specific cross-section through a slope and formulate an expression for the factor of safety, as shown in Figure 1.

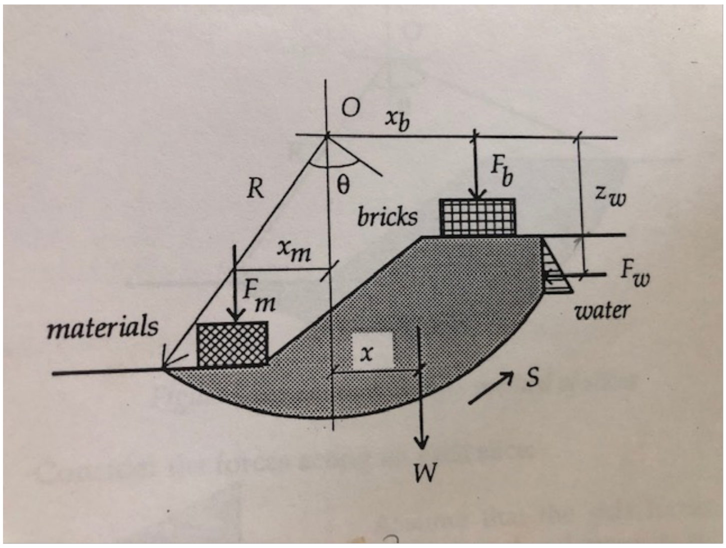

Figure 1. Cross section of slope stability problem

A reduced scale model was used in order to more effectively demonstrate the repose angle, and calculate the safety factor for the small-scale, classroom model. Thereafter, the students were asked to formulate an expression of the safety factor for various scenarios: dry, or undrained conditions, and loading after having installed a series of geosynthetic layers in the model at a specific spacing.

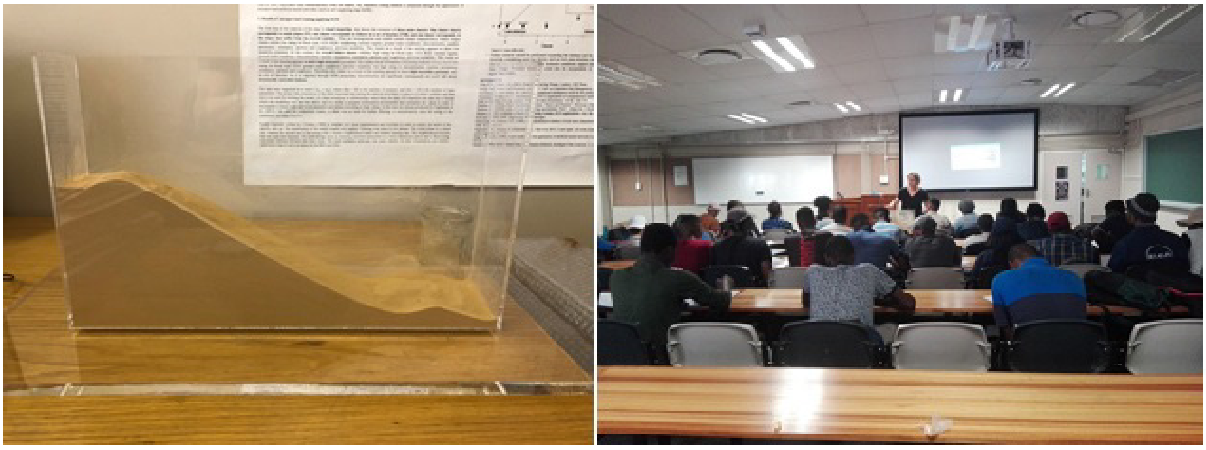

Figure 2. a) Slope model that served as a classroom model in order to show the repose angle of the dry sand slope, b) demonstration of function of reinforcement through the use of the small-scale model slope

It was observed that the students appreciated the effect of geosynthetic engineering in both applications, as they proved through their calculations the benefit of each solution. However only half of the class engaged in the first problem solving activity, and one third of the class attended the class demonstration and problem solving activity on slope stability analysis. It was also remarkable that when they were asked as part of the survey on the application of geosynthetics, none of the students referred to the acceleration of consolidation rate.

3.2 Survey design

In order to investigate the outcomes of this pedagogical process, several types of data were collected and analysed. Firstly, the students' completion of the example problems was observed with a view to investigating the extent to which they were able to demonstrate how the use of geosynthetics could assist in preventing slope failure or accelerating consolidation time.

Secondly, the results of the student survey were analysed in terms of the students' perceptions of and attitudes towards geosynthetics, after having gone through the pedagogical intervention described. These survey results provide insight into students' misconceptions surrounding geosynthetic engineering – as well as their intentions to utilise geosynthetics in the future. This final point – intention to use geosynthetics in the future – was correlated with students' actual use of geosynthetics in a design project that the students undertook during the course of the semester. This design project was intentionally open-ended, and students were not required to use geosynthetics.

The survey and student presentations and reports were analysed using the techniques of content analysis. Content analysis is a data analysis strategy that turns qualitative data into quantitative data through a process of counting the number of appearances of particular content. This is done through a process of coding, or "systematic, objective, quantitative analysis of message characteristics" (Neuendorf, 2002). Content analysis has been applied to a wide and diverse range of research interests, particularly in linguistics and media studies. In this research, it was used to identify what the sampled student group identified as most salient in their thinking about geosynthetics.

All students whose participation is reported on herein gave written and informed consent for their participation to be included in this research. This includes their design projects as well as the surveys they completed. Students had the option to refuse to participate in this research – without any adverse repercussions. Moreover, they could withdraw their participation at any point during the research process.

4 Results and Discussion

4.1 Student perceptions and attitudes towards geosynthetics: Survey results

The survey included three yes/no questions: students were asked to anonymously indicate whether they had done the prescribed reading on geosynthetics, whether they had attended the guest lecture, and whether they had or would consider geosynthetics as a possible solution in the design project they were required to complete in the same semester. In this regard, all but four students admitted that they had not read the prescribed text. Of the four who had, two indicated that they had only read parts of the prescribed reading. In contrast, all but four students who completed the survey had attended the guest lecture. Two students indicated that they had attended the guest lecture and that they had read at least part of the prescribed text, while two students said that they had done neither. Regarding the third question (whether they had or would consider using geosynthetics in their design project), only one student said they would not consider or had not considered using geosynthetics in the future.

Thereafter, the survey consisted of four open-ended questions below:

1. How would you define geosynthetics?
2. What is the value/role of geosynthetics in the work of a geotechnical engineer?
3. What kind of geotechnical engineering problems/challenges do you think geosynthetics can address/solve?
4. Comment on your likelihood to use geosynthetics in future (please elaborate on your answer)

The first question was aimed at ascertaining the students' understanding of the concept. Before analysing this question, we identified four key aspects of a definition of geosynthetics.

a) At its most basic, geosynthetics are a family of materials or products.
b) These materials are synthetic or, more accurately, polymeric.
c) The materials are in sheet form.
d) Geosynthetics may either have an open structure and provide high tensile strength, or are closed sheets used as impermeable drainage barriers.

In this regard, of the 52 students who completed the survey, 49 were able to identify the last aspect of the definition, that is, the function of geosynthetics. It should be noted that a majority of these noted the function of slope reinforcement, which was the function foregrounded in the project, in the guest lecture, and in the problem-solving exercise, but is not the only function of geosynthetics. Also, 45 students identified geosynthetics as constituting a family of materials or products, but only 31 included the polymeric or synthetic nature of geosynthetics in their definition. Only five students referred to the planar form of geosynthetic materials. This means that while few students were able to provide a comprehensive definition of geosynthetics, a large majority were at least aware of the materiality and function of geosynthetics.

Nonetheless, there were some misconceptions evident in the definitions provided. For example, one student argued that geosynthetics “is the study of geotechnical engineering which is based on determining way[s] to … stabilize soil generally”, and another suggested that “it is the science [of] making slopes to be more stable, by using methods that makes the FS to be above 1 and design slope that would not fail”. A third student contended that geosynthetics “are materials that are used to stabilize any slope *upon failure*” (emphasis added). The first two examples here suggest that the students confuse geosynthetics as products with the engineering, through the study of soil mechanics, in which these products are deployed. The third example fails to appreciate that geosynthetics are not only used for rehabilitation where failure has occurred (though this was the focus of the design project and of some aspects of the guest lecture) but can also be used in the initial design solution.

The following two questions of the survey asked students about the role, or value, of geosynthetics in geotechnical engineering design and about the kinds of geotechnical engineering problems, or challenges, that could be addressed, or mitigated by using geosynthetics. There was significant overlap in the responses to these two questions and, as such, they were analysed together. The responses to these two questions broadly fell into two broad categories: the applications of geosynthetics and the advantages of using geosynthetics. Regarding the applications of geosynthetics, the student participants identified various applications of geosynthetics, ranging from general applications to more specific or specialised applications. Table 2 provides a summary of the content of the responses obtained, as well as an indication of the number of students that raised that particular point in their response to one or both of the two questions. Regarding the advantages of geosynthetics, the student participants identified several advantages; these are listed in Table 3.

Table 2. Survey results regarding applications of geosynthetics

Application identified in students' response	Function according to IGS nomenclature	Frequency of response
Slope stability	Soil reinforcement	31
Soil reinforcement	Soil reinforcement	28
Erosion protection	Erosion control	24
Slope failure and rehabilitation	Soil reinforcement	18
Filtration/Drainage/Seepage	Filtration / drainage	12
Preventing infiltration/ingress of liquids	Barrier	8
Retaining walls and backfill	Soil reinforcement	7
Landslide protection	Erosion control/soil reinforcement	6
Seismic protection	Soil reinforcement	2
Rock falls	Erosion control	2
Settlement	Drainage	1
Underwater foundations	?	1

The final question in the survey asked students to comment on the likelihood of them using geosynthetics in the future and to elaborate on their answer. To this end, the vast majority of students indicated that they would use geosynthetics and a quarter of the respondents suggested that they were “very likely” or would “strongly consider” or “definitely” use geosynthetics in the future. In most instances, the student participants cited the previously listed advantages of geosynthetics as the reason for their answer. However, there were some students who tied the use of geosynthetics specifically to their future career goals and aspirations. For example, one student stated: “I will most probably use geosynthetics in the future for I am looking to further my career in geotechnical engineering”. Another was even more specific about their future career plans: “chances are that after graduation I will work in a mining company which is open cast. The slope stability of the mine will be very important, hence I will use the geosynthetics to improve the slopes while the mining is operating and also for the haul roads in the mine”.

Table 3. Survey results regarding advantages of geosynthetics

Advantage	Frequency of response
Reduced cost (particularly regarding material replacement)	10
Overcoming the limitations of natural materials	8
Increased/high tensile strength	8
Reduced settlement and increased bearing capacity	6
Easy handling and use	6
Improved (minimised) permeability	5
Enabling design of steeper slopes	4
Increased Factors of Safety	3
Pore water pressure reduction/hydraulic pressure dissipation	3
Reduced labour	2
Reduced CO_2 emissions	1
Variety of types and applications	1
Reduced material volumes	1
Durability	1
Promotion of vegetation	1
Reduced time	1

Yet, some students were less enthusiastic in their responses. One student suggested that they would use geosynthetics if the need arose, but that their interest in geotechnical engineering was minimal. Finally, one student provided a particularly pragmatic, but insightful answer to the question by arguing that they would be very likely to use geosynthetics "depending on the situation, location, and other alternatives as well as the customer".

4.2 Students' design with geosynthetics

During the semester over which this study was conducted, the students were also required to complete a mini-design project, which required them to propose a design solution for road slip repair where failure was induced due to the combined effect of erosion and seepage and poor in-situ fill materials (Simpson & Ferentinou, 2020). The students were not required to pursue any particular solution and the design problem was entirely open-ended. The design project was undertaken in groups of three or four students. Many groups opted to incorporate geosynthetics into their design project – even before the guest lecture and the specific input on geosynthetics was provided. However, their initial design solutions (proposed before the guest lecture and before the survey discussed above was administered) suggested numerous misunderstandings and misconceptions about both geosynthetics and slope failure more generally.

For example, while many groups used RocScience to design geosynthetics into their proposed solution, only a small number (fewer than 5, out of more than 20), placed their geosynthetics horizontally. Instead, most groups' designs saw the geosynthetic materials placed perpendicular to the slope face, revealing a lack of understanding of the process of installing geosynthetics or a lack of thought given to constructability. In addition, most groups did not extend the geosynthetic layers into the slope such that the geosynthetic materials intersected the slip failure surface. This suggested a lack of understanding of the purpose of geosynthetic materials and a lack of understanding of the mechanics of slope stability. However, it is not entirely expected from 3rd year students to be able to consider the overall stability of the slope soil bodies whose failure planes cut the reinforcement layers, in addition to those bodies which include the reinforced earth body (Figure 3) or the tensile forces required for the overall stability.

Because of this failure to extend the geosynthetic materials into the slope, many groups, even after adding geosynthetic layers into their design, failed to obtain a satisfactory factor of safety. As a consequence, they reduced the slope angle, which resulted in more space being utilised in the design, and the geosynthetic materials effectively being wasted. This again highlighted the students' lack of understanding of the mechanics of slope failure and their misrecognition of the advantage of geosynthetics that some of them subsequently raised in the survey results, namely, steeper slope design and the concomitant benefits of reduced space utilisation and reduced materials requirements. Also, because the students did not extend their geosynthetic layers into the slope, they needed to include numerous layers with spacing of, in some instances, only one metre. This resulted in expensive over-design, and again highlighted the shortcomings in the students' understandings both of the mechanics of slope failure and of the purpose and value of geosynthetics within geotechnical engineering design. In some cases, these misconceptions had been ironed out by the final design presentations, but in many, they remained evident even in the final design presentations.

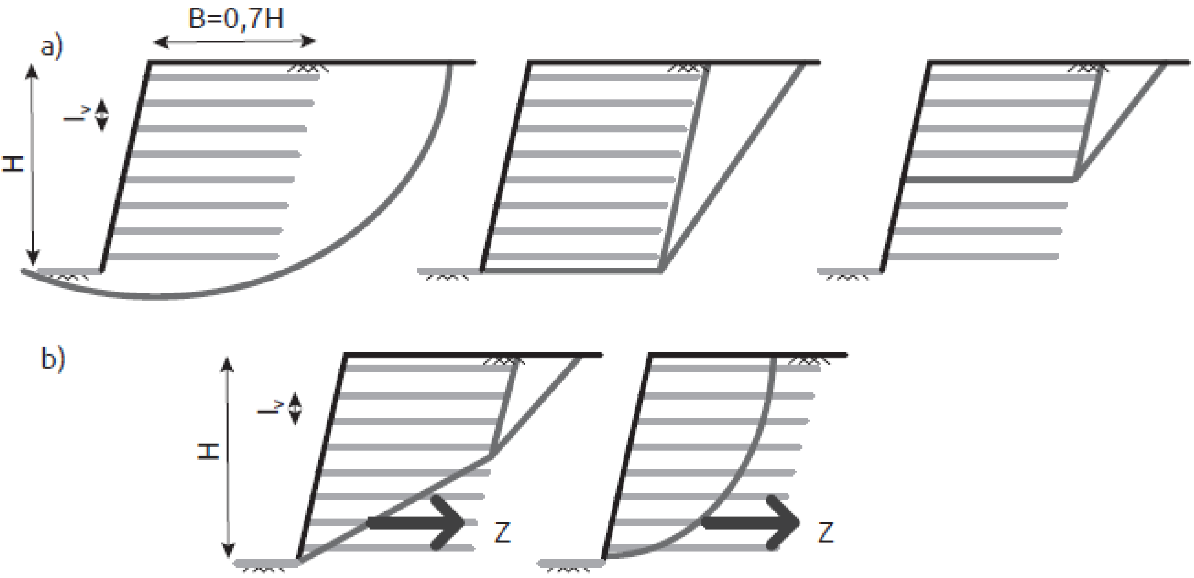

Figure 3. Slip planes for the verification of overall stability: a) outside and/or along the reinforcement layers; and (b) which intersect the reinforcement layers (adapted from Ziegler, 2018)

5 Conclusion

This paper has presented an approach to the integration of geosynthetics into a geotechnical engineering module that forms part of a civil engineering degree programme. As argued by the International Geosynthetics Society, graduating engineering students have little or no exposure to the appropriate use of geosynthetics in engineering practice. To address this issue, in this paper, we present an example and lessons learned of how the core principles of geosynthetics can be incorporated into the existing curriculum. As part of this approach, we proposed a combination of lectures, demonstrations, class problems, and a mini-project which provided a project-based approach to our teaching method.

As was seen in the results obtained, in both the in-class problem and in the survey results, students were able to do quite well in terms of explaining the functions and applications of geosynthetics in theory. Moreover, they demonstrated significant intention to use geosynthetics in the future. However, their actual use of geosynthetics, as evident in the design project, showed that they still held various misconceptions about the application of geosynthetics in practice.

The authors' reflection after the application of the proposed activities, is summarised as follows:

- There is a need to make reading selected literature on geosynthetic materials compulsory, through relevant assessment quizzes, or small tests.
- It is necessary to dedicate more time, though a series of formative lectures, to the functions and applications of geosynthetics, perhaps in the form of a workshop, as this would require more contact hours outside the formal timetable.
- It may be useful to develop one small project where the elements of design with geosynthetics are scaffolded and developed, so that the students get sufficient exposure to the elements of the design of one particular application. To this end, the support of the local IGS chapter (GIGSA), will be a significant benefit to the students.

Nonetheless, these practical challenges can be resolved through a greater number of tasks that require use of geosynthetics and, ultimately, through several years of practical work-based experience in using such geosynthetics. The ultimate benefit of these efforts would be in the form of engineering graduates with an applied knowledge of geosynthetics who can contribute to mitigating many of the negative impacts of geotechnical engineering practice.

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Authors' bios

Maria Ferentinou, University of Johannesburg, South Africa

Dr. Maria Ferentinou is an Associate Professor at the University of Johannesburg in the field of Geotechnics – Engineering Geology. She holds a BSc degree from the University of Patras, and a PhD from the National Technical University of Athens. Her main research focus lies on slope stability assessment, study of rock engineering systems, and application of artificial intelligence in geotechnics. Currently she is engaged into slope monitoring and sinkhole propagation monitoring using fiber bragg gratings and small scale physical models. Her profound love for teaching has evolved in developing a research interest towards engineering education, and pedagogical strategies aimed at better preparing engineering students. She has been a member of the South African Society for Engineering Education since 2017.

Zach Simpson, University of Johannesburg, South Africa

Dr. Zach Simpson is a Senior Lecturer in the Faculty of Engineering and the Built Environment at the University of Johannesburg in South Africa. He holds a PhD in Education from the University of Cape Town in South Africa, specialising in engineering education. His research focus areas are engineering education, higher education studies, multimodal social semiotics and academic literacies. His work is largely concerned with how students come to understand and use the meaning-making practices of engineering. He has been a member of the South African Society for Engineering Education since 2011, and is editor-in-chief of the journal SOTL in the South.

Highlighting Links among Geology, Index Properties and Mechanical Behaviour at the Beginning of a First Course in Soil Mechanics

M. Matos Fernandes & J. Couto Marques

CONSTRUCT, Faculty of Engineering (FEUP), University of Porto, Porto, Portugal
matos.fernandes@fe.up.pt, jmarques@fe.up.pt

ABSTRACT: The paper reports the experience of the authors teaching Soil Mechanics to undergraduate students. The focus is on the first three or four weeks of the semester. The practice consists of establishing, for the main soil archetypes (sedimentary sands and clays and residual soils), a strong relationship between: i) geological conditions prevailing during soil formation and thereafter; ii) soil physical-identification parameters; iii) basic trends of mechanical soil behaviour. The purpose is to explain – through simple mental models – how to interpret the basic physical and geological characterisation of the soil, in order to anticipate the main difficulties for a given (simple) project. These difficulties may include insufficient bearing capacity, very large and delayed settlements (soft clay), large settlements under seismic loading (loose sands), etc. In light of these difficulties, some solutions (just the main idea) are discussed (soil reinforcement, acceleration of settlements, vibro compaction, deep foundations instead of shallow foundations, etc.). The experience of transmitting this perspective is that these early classes enable: i) a better apprehension of the subsequent truly mechanical chapters; ii) a proper evaluation by the students of the technical and practical relevance of the subjects; iii) a strong motivation for the study of the discipline.

Keywords: Soil physical characterisation, Geological conditions, Trends of mechanical behaviour

1 Introduction

The traditional Soil Mechanics syllabus in a Civil (or Mining) Engineering degree course starts with an introductory section (with one or more chapters, according to the structure of the adopted textbook) on the soil physical parameters, as well as certain chemical-mineralogical features of clays. The physical parameters comprise the basic indices that express the proportion of the weight and volume of the three phases of the soil (water content, void ratio, porosity, degree of saturation), the various unit weights (total, dry, buoyant and solid particle) and also the identification characteristics: the particle size distribution curve and the Atterberg limits. These identification characteristics are the basis for the application of the Unified Soil Classification (Casagrande, 1948).

Then, the effective stress principle is introduced, followed by the chapters that deal with the soil strength and stiffness under various types of loading (confined, isotropic, triaxial in compression or extension, simple shear, drained and undrained). For non-saturated soils, the stresses in the three phases of the soil are explained to take into account the suction effect, and the behaviour under suction controlled conditions is discussed for the various types of loading. These aspects are covered in two ways, which correspond to the so-called Classical and Critical State approaches.

In most textbooks, the treatment of the physical parameters is essentially presented with reference to their laboratory determination, without a clear intention to establish a strong connection to the soil formation process in Nature and to the geological scenario prevailing at that time and site. Similarly, in those introductory chapters most textbooks lack the intent to explain how the interpretation of this set of physical parameters enables to anticipate some trends of the soil mechanical behaviour.

In our opinion, such options are going to limit the students' understanding of the future chapters on soil mechanical characterization due to the absence of awareness for what determines, in concrete cases, the higher or lower strength/stiffness of a particular soil. This point is more pertinent to the classical approach than to Critical State Soil Mechanics, but it applies to both.

Based on the physical characterisation of the constituent soils of the various layers and the geological context/scenario of the site, an experienced geotechnical engineer is often able to anticipate the essential problems that the soil mass presents and, consequently, is capable to take a number of major design decisions for a given project. The specific (quantitative) aspects of design naturally require the experimental determination of mechanical (and sometimes hydraulic) parameters, with knowledge and observance of the theoretical fundaments of Soil Mechanics.

It seems to the authors pertinent to raise the following question: is it possible to train students to anticipate the essential features of the mechanical behaviour of the ground mass, particularly those more unfavourable, based on the interpretation of soil physical characterisation data and of the site geological context? For clarity, one must delimit the context of the question: we are considering projects that involve ground with horizontal surface, to be loaded by civil engineering structures such as tanks, silos, embankments for transport infrastructures or for large industrial-logistic areas, or foundations of current structures. Complex geotechnical works are excluded, such as stabilisation of natural slopes, deep excavations and others.

This is the object of this paper, based on the experience of the authors in teaching Soil Mechanics to undergraduate students at the University of Porto. This experience allows to answer affirmatively to the question formulated above, as will be explained herein.

2 The current approach for the treatment of physical parameters

The approach adopted in the first chapters of most courses and textbooks is essentially focused on the characterization of physical parameters (with special laboratory emphasis) and omits, or gives insufficient emphasis, to the following essential questions for sedimentary soils:

i) what controls or characterises the physical state of the soil shortly after sedimentation?

ii) which physical parameters can be assigned to the soil shortly after sedimentation?

iii) which natural processes act mechanically (i.e., exert loading) on the soil following sedimentation?

iv) what relation do these processes and the physical state of the soil have with the geological scenario/context, in particular with the age of the sedimentary deposit?

v) what is the effect of these processes on the soil physical parameters?

vi) how does the alteration of the physical parameters influence, in qualitative terms, the mechanical response of the soils when loaded by simple Civil Engineering structures?

These questions are now discussed for the two sedimentary soil archetypes: sands and clays.

3 Sandy soils

Figure 1 schematically shows that the grain size distribution determines the soil void ratio interval e_{max} - e_{min}. However, it is rare to find in textbooks an additional explanation concerning the following items, which are essential for starting to understand the mechanical behaviour of granular sedimentary soils:

i) at the "moment" of sedimentation each soil assumes its maximum void ratio, e_{max};

ii) due to natural loading (weight of new sediments, earthquakes, etc.), the *in situ* void ratio moves progressively away from e_{max} and tends to e_{min};

iii) the reduction of void ratio occurs due to particle rearrangement, with progressive elimination of unstable equilibrium situations, initially very numerous;

iv) this structural alteration remains essentially preserved, even when Nature removes by erosion the overlying layers that caused that evolution;

v) the reduction of void ratio, expressed by an increasing density index, I_D, has a clear mechanical consequence, increasing stiffness (and strength) of the soil.

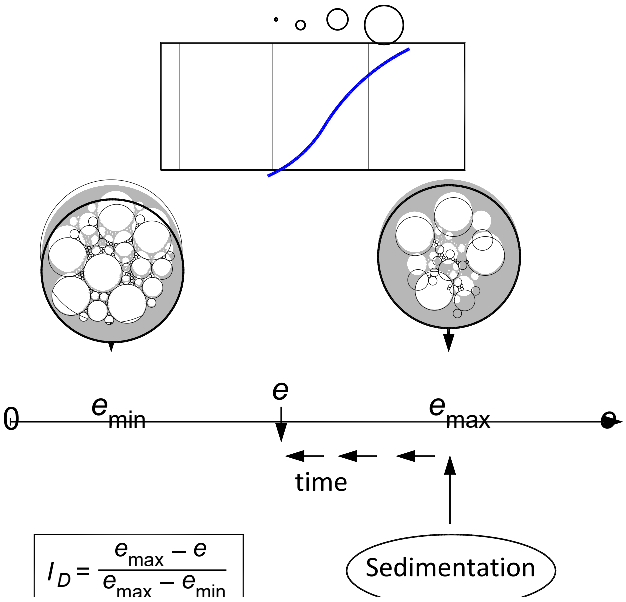

Figure 1. Grain size distribution *vs.* void ratio interval amplitude (adapted from Matos Fernandes, 2017)

As to what concerns item i), one should bear in mind that the test for the determination of e_{max} is a laboratory simulation, naturally simplified, of the sedimentation process. This fundamental aspect is seldom emphasized in most textbooks. In complement, the test for determining e_{min} intends to replicate an intense and repeated natural loading process, by dynamically combining vibration and compression.

After discussing the questions previously listed, it is natural and appropriate to highlight, for the first time in the course, the importance of the soil stress history in its mechanical behaviour and, then, to conclude that ancient soils typically tend to be more sound than recent soils. With a small additional step, the site geological scenario can be associated, by adding that Holocene age sand deposits mostly comprise soils with low density indices. And, depending on the geographic conditions, to comment on what happens in successively more ancient formations, from the Plio-Pleistocene age, the Miocene age, etc. In complement, it is simple and timely to explain how recent deposits exhibit deficient behaviour under seismic loading (mentioning settlements and leaving liquefaction for a later occasion, for obvious reasons) and to refer, for the first time, to the methods of treatment that may prevent such behaviour, while also improving the response to static loading.

4 Clayey soils

Figure 2 schematically illustrates the Atterberg limits, controlled by the fine fraction and its mineralogical type. In the authors' opinion, in conjugation with the introduction of the Atterberg limits, the following essential points should be immediately added for a preliminary understanding of the mechanical behaviour of sedimentary fine plastic soils:

i) at the "moment" of sedimentation, each soil approximately assumes its liquid limit, w_L;

ii) as a result of natural loading conditions (the weight of new sediments), the void ratio progressively decreases;

iii) the void ratio decrease implies the reduction of the water content, which progressively deviates from w_L;

iv) this structural alteration is essentially preserved, even when Nature removes by erosion the overlying layers whose weight led to such evolution;

v) the reduction in water content, as expressed by the increase of the consistency index, I_C, has an immediate mechanical effect: it increases the stiffness (and strength) of the soil.

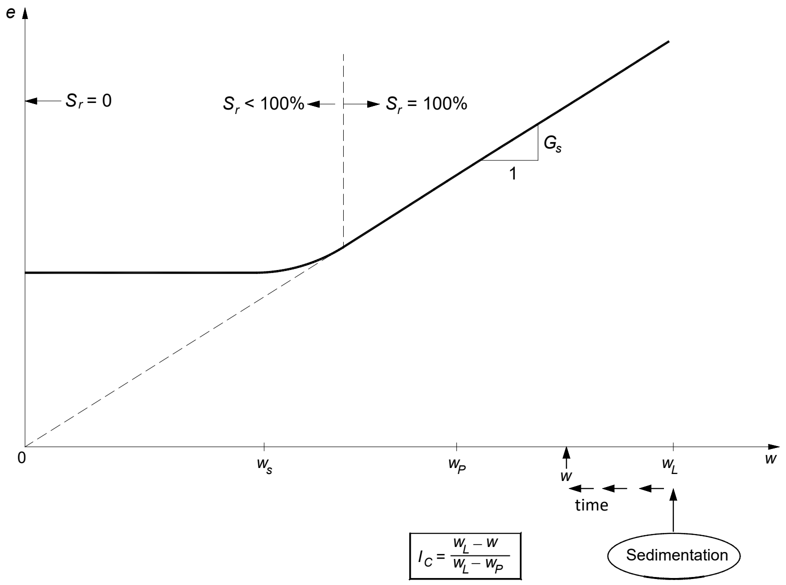

Figure 2. Atterberg limits (adapted from Matos Fernandes, 2017)

In relation to item i), one should discuss why the tests for the determination of w_L (Casagrande and fall-cone tests) do not involve a laboratory simulation of soil sedimentation – as opposed to e_{max} for sands. The reason is the practical infeasibility of such simulation for very fine soils. The (rather peculiar!) above mentioned tests have been conceived for a fast and simple identification of the water content for which the soil consistency is extremely low. Therefore, rather than stating that w_L is the water content after sedimentation, it is more appropriate to say that immediately after sedimentation each soil approximately assumes a water content value close to its liquid limit. It is well known that important exceptions exist to this statement, with quick clays being the more notorious. Such exceptions, which may be treated at a later stage in the course, should not prevent this association to be emphasized and their logical consequences to be extracted.

In a similar manner to what has been discussed for sands, it is opportune to identify the importance of the soil stress history on the mechanical behaviour, by outlining that ancient soils tend to be typically more firm than recent soils. This is just a small step away from associating the site geological scenario, by adding that Holocene age clay deposits mostly comprise soils with low consistency indices. And, depending on geographic conditions, to comment on what happens in formations progressively more ancient, from the Plio-Pleistocene age, the Miocene age, etc.

Observing and commenting upon subsoil profiles, namely showing the evolution in depth of the water content and its position in relation to the w_L-w_P interval, such as represented in Figure 3, may be very useful in this context (Lambe and Whitman, 1979; Burland, 1990). The same can be said about Figure 4, which collects the sedimentation-compression curves (Terzaghi, 1941) of 20 normally consolidated deposits, from extremely recent muds to late Pleistocene age soils over 1000 m deep, and highlights the consolidation of clay by gravitational loading (Skempton, 1969).

At this early phase, it is not difficult to explain that, such as in Nature the process of reduction of water content/void ratio is very slow, the same happens when a very recent clayey layer, thus located close to the surface, is loaded by a Civil Engineering structure. And to make a first reference to methods that permit to accelerate this volumetric deformation, after explaining that in most cases time-delayed settlements compromise the normal exploration of works.

5 Residual soils

Taking into account the regional importance of residual soils from granite in NW Portugal, this preliminary stage of the course also presents a discussion about their typical physical indices, as well as their specificities when compared with sedimentary soils (extreme heterogeneity, cemented structure, influence of relict joints) and their behaviour trends (Viana da Fonseca et al., 1994).

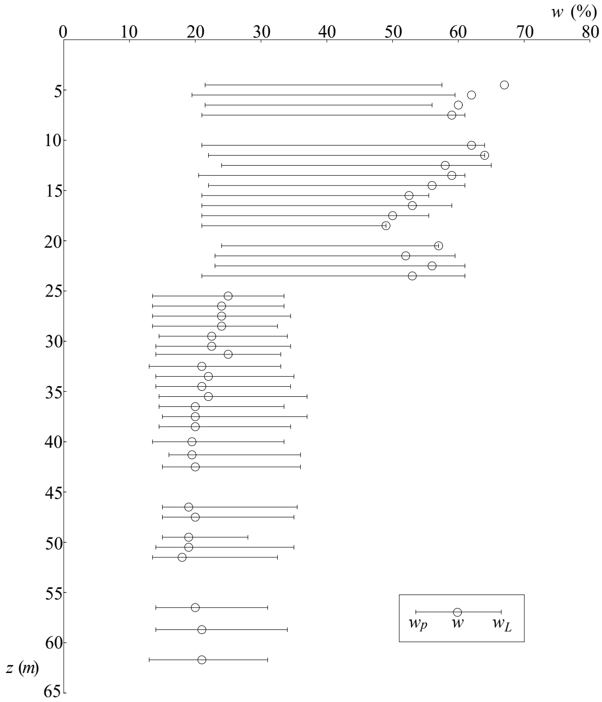

Figure 3. Water content and liquid and plasticity limits over depth, Troll Oil Field, North Sea, Norway Coast (adapted from Burland, 1990)

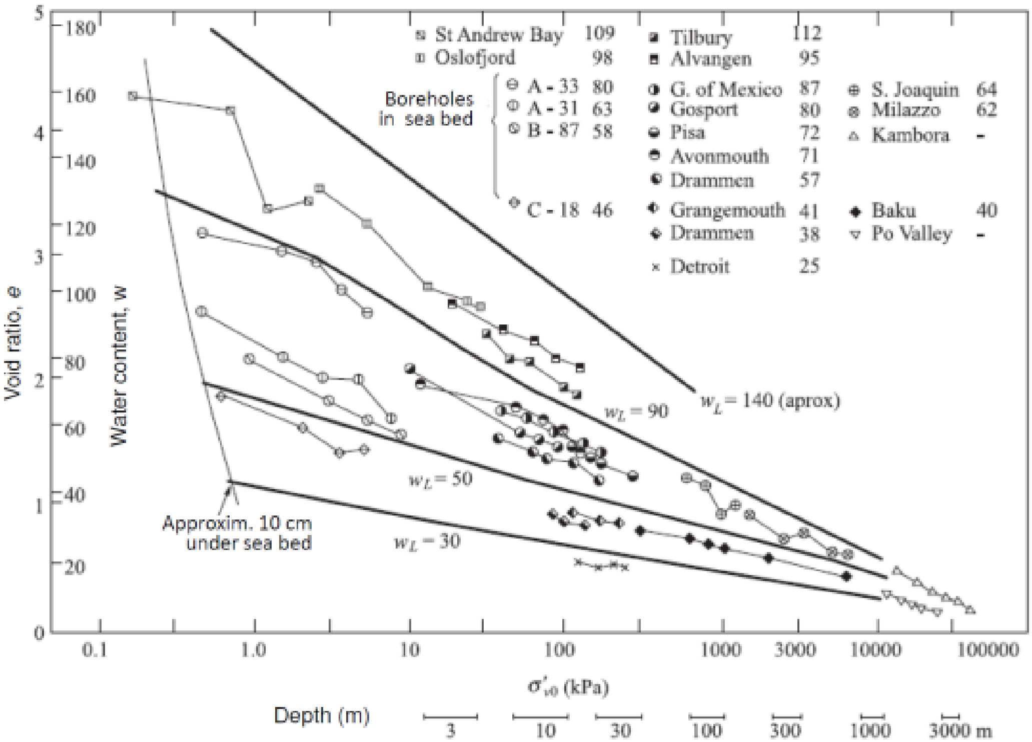

Figure 4. Sedimentation compression curves from normally consolidated fine sediments (Skempton, 1969)

6 Problem sheets: Examples

Annex 1 includes two examples of problems presented to the students about the soil physical indices and the behaviour patterns previously discussed. These problems are proposed for the 2nd and 3rd weeks of a semester course of 13 weeks.

This form of association of physical indices and geological context with trends concerning mechanical (and also hydraulic) behaviour is developed and extended as this behaviour is treated in subsequent chapters with a truly mechanical approach.

This may be ascertained by the example included in Annex 2, extracted from a final exam. It can be seen that the questions involve aspects such as: i) permeability; ii) normally consolidated and overconsolidated soils; iii) (positive or negative) dilatancy; iv) liquefaction potential; v) evolution with depth of undrained shear strength; vi) solution techniques to accelerate consolidation or increase the density of loose granular soils; vii) foundation soil failure under undrained loading. A proposal for answering those questions is included at the end of the annex.

7 Conclusions

In the paper, a gap has been identified in the traditional process of teaching/learning Soil Mechanics.

This gap limits the understanding that the mechanical behaviour – expressed by a series of abstract concepts – is totally controlled by the physical/geological soil characteristics and these physical/geological characteristics are much easier to realise because they are intrinsically concrete!

Most of the main decisions of an experienced engineer are made on the basis of the interpretation of the site geology and of the physical/identification parameters of the relevant soil layers.

The characterisation via mechanical lab and field tests and the calculations are essential in design, but seldom lead to significant changes in the conception of the solution based on the aforementioned interpretation.

The acquisition of expertise to assess the "field atmosphere" usually requires years of experience but can be prepared at the University. This requires training for the ability to interpret the geological conditions and the physical-identification indices and to associate them to trends of the soil mechanical behaviour. This training should begin even before studying the approaches that quantitatively characterise the mechanical soil behaviour. But it should continue and be improved in parallel with these approaches!

This strategy has a number of relevant advantages:

- it trains the *eagle eye*: much can be extracted from the physical indices to assess the expected mechanical trends;
- it establishes an impressive background for the subsequent (mechanical) chapters, whose subjects become more "realistic";
- it is a good opportunity to introduce solutions to prevent undesirable soil behaviour (just the basic idea);
- it gives rise to very vivid classes, in which students gain enthusiasm because they discuss real engineering problems;
- those simple but powerful ideas are easier to remain retained in the future, as a general knowledge.

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Annex A

Example 1 - Figure A1 displays a formation of sedimentary origin over which a petrochemical complex will be constructed. The top layer corresponds to an existing fill placed about 50 years ago.

The project will include a new fill, of very large dimensions in plan, which will raise the soil surface from elevation +2.00 to elevation +4.00. Over this extended embankment, oil storage tanks will be constructed. Such structures are tolerant to moderate foundation settlement. The site is within a seismic zone.

Table A1 shows the physical and identification characteristics obtained from samples taken from the three layers underlying the ancient fill. The order of the soils in the table and the succession of the layers in the figure are not necessarily coincident. Take γ_w = 9.8 kN/m^3. Assume that all soils are saturated.

Table A1. Soil parameters

Soil	e_{min}	e_{max}	w_L (%)	w_P(%)	γ_s (kN/m^3)	w (%)
1	-	-	50	25	26.0	22
2	-	-	70	30	25.7	65
3	0.28	0.90	-	-	26.1	15

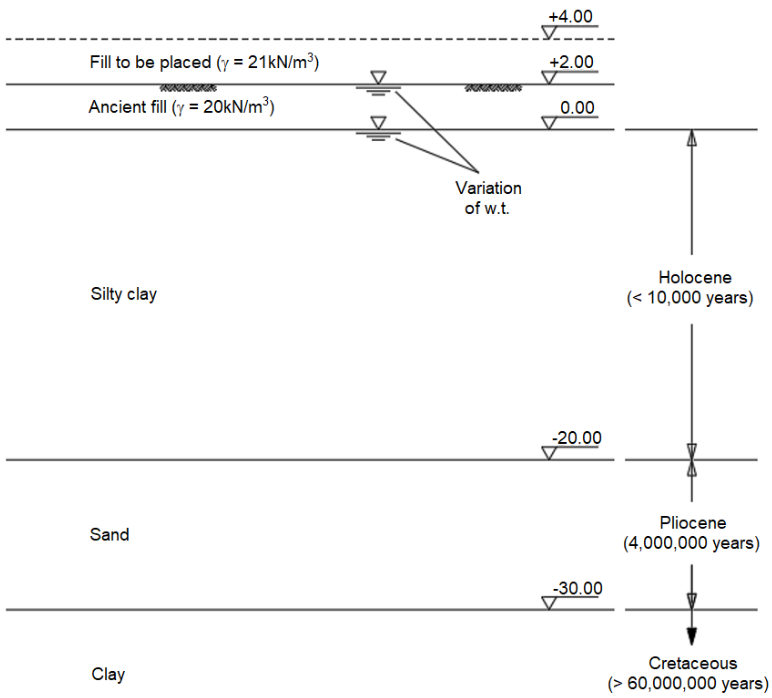


Figure A1. Geological-geotechnical profile

a) Calculate the void ratio and the unit weight of the three soils of Table A1. Present the deduction of the expressions employed.
b) Establish the correspondence that you find more reasonable between the layers of Figure A1 and the soils of Table A1 and describe them using at most one line of text for each soil. Present all the parameters required for your answer and the respective calculation. Justify.
c) Select one of the parameters of Table A1 and describe how can be carried out its experimental determination.
d) In case of occurrence of a strong earthquake, will any of the soils exhibit deficient behaviour? In the affirmative case, identify the soil(s) in question and justify. Describe that behaviour and explain how it can be prevented.
e) Due to the placement of the embankment, will any of the soils have large and delayed settlement? In the affirmative case, identify the soil(s) in question and justify. Describe a procedure for preventing such behaviour.
f) Which of the soils of the table would you select as adequate fill material for the construction of the embankment? Justify.

Example 2 - Figure A2 represents the geological-geotechnical profile of a site where a 30 m high earth fill dam will be constructed. The bedrock consists of granite whose upper zone is weathered. The contact zone of the granite rock with the overlying soil layer C is very irregular, which suggests that this layer might be a residual soil.

Table A2 presents some physical characteristics of the constituent soils of the three layers. Figure A3 displays grain size distribution of the soils of the table. Note that the order of the soils in Table A2 and in Figures A2 and A3 does not necessarily coincide. Assume that all soils are saturated. Take γ_w = 9.8 kN/m^3.

Table A2. Soil parameters

Soil	w_L (%)	w_P (%)	γ_s (kN/m^3)	e_{min}	e_{max}	w (%)
1	---	---	26.1	0.40	0.98	19
2	34	25	25.8	---	---	23
3	---	---	26.0	0.20	0.89	18

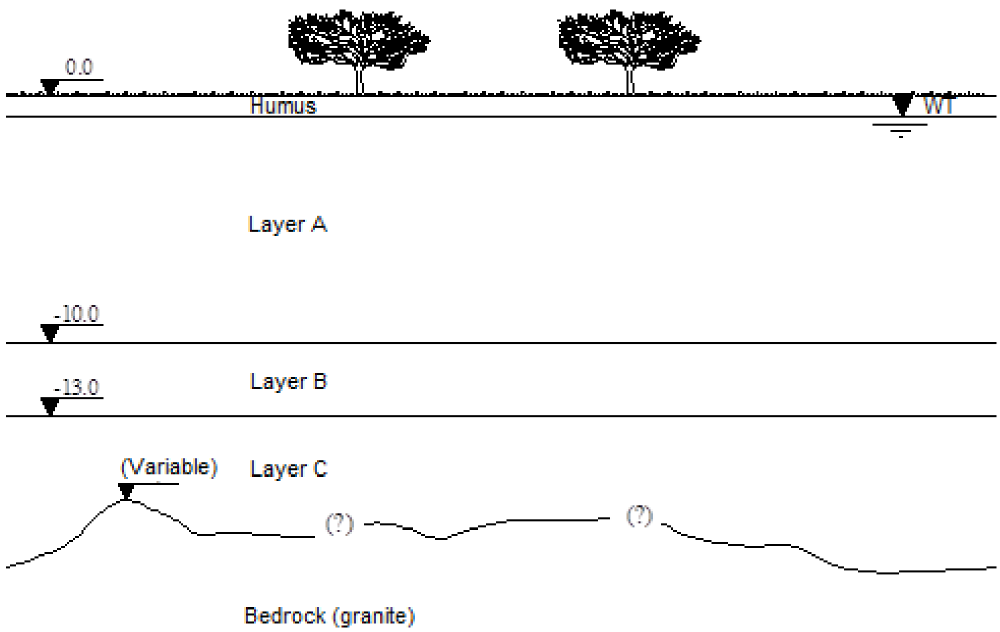


Figure A2. Geological-geotechnical profile

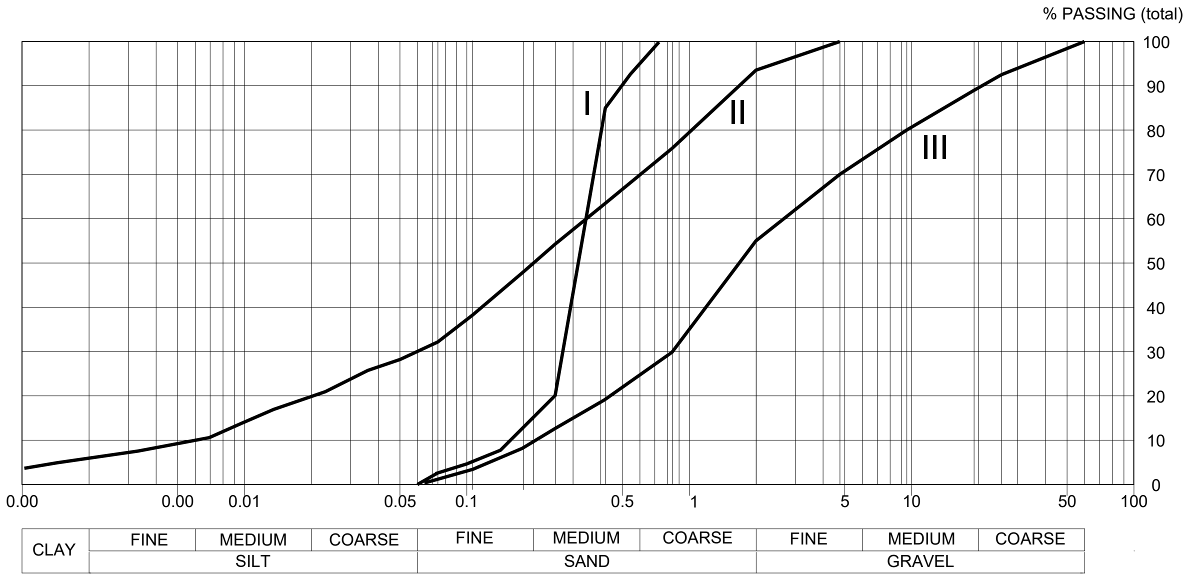


Figure A3. Grain size distribution curves

a) Establish the correspondence between the soils 1 to 3 of Table A2, the layers A to C of Figure A2 and the grain size distribution curves I to III of Figure A3. Present the deduction of the expressions employed. Justify.

b) Describe each of the soils for Civil Engineering purposes, using at most six words.

c) In case of occurrence of a strong earthquake, will any of the soils exhibit deficient behaviour? In the affirmative case, identify the soil(s) in question and justify. Describe that behaviour and explain how it can be prevented.

d) Will any layer exhibit large and delayed settlements due to the load applied by the dam? In the affirmative case, identify the soil(s) in question and justify. Describe a procedure for preventing such behaviour.

Annex B

Example 3 - Figure B1 presents the geological-geotechnical profile of a geologically very recent alluvial valley that is going to be crossed by a railway line. Part of the line will be constructed over an embankment and part on a bridge with pile foundation. The work is located within a seismic zone. Figure B2 shows the soil layout in the embankment zone.

Table B1 provides physical parameters determined from samples collected in the four soil layers. The order of the soils in Table B1 and in Figures B1 and B2 does not necessarily coincide. Note that in Figure B1 the horizontal scale is much smaller than the vertical scale.

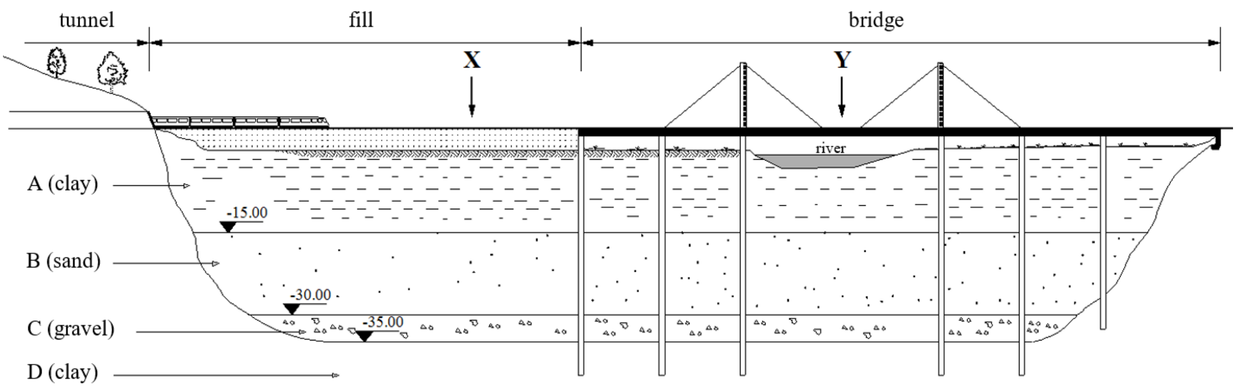


Figure B1. Geological-geotechnical profile

Table B1. Soil parameters

Soil	% clay	% silt	% sand	% gravel	γ_s (kN/m^3)	γ (kN/m^3)	e_{min}	e_{max}	w_L (%)	w_P (%)
1	0	5	83	12	26.0	18.5	0.25	0.95	-	-
2	0	0	4	96	25.8	20.5	0.36	0.89	-	-
3	40	45	15	0	26.3	15.0	-	-	88	40
4	55	35	10	0	26.1	20.9	-	-	53	22

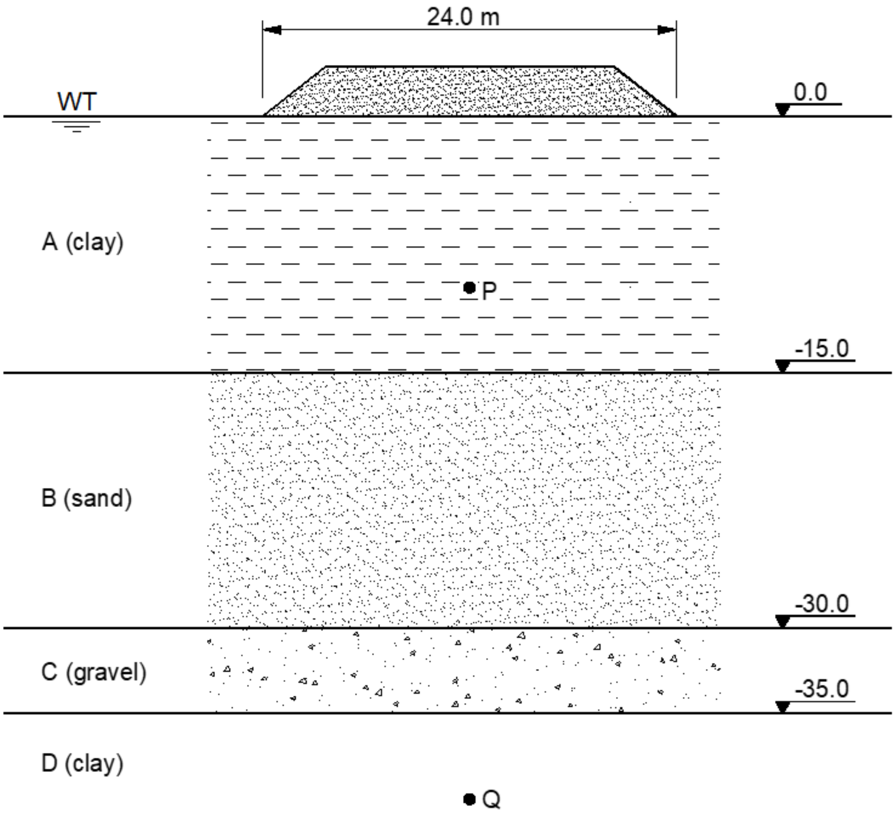


Figure B2. Soil layout in the embankment zone

a) Calculate the void ratio and the water content of the soils of Table B1. Present the derivation of the expressions employed. Admit that all soils are saturated. Take γ_w = 9.8 kN/m^3.

b) Establish the correspondence that you find more reasonable between the soils of Table B1 and the layers of Figures B1 and B2. Present the calculation of the parameters utilised to establish the correspondence.

c) Are the clay fractions of the soils 3 and 4 of the same mineralogical type? Justify.

d) Sort the four soils in increasing order of permeability. Justify.

e) Will any of the soils be probably heavily overconsolidated? How could you ascertain experimentally in the lab your answer? How would have to be the experimental result in order to confirm the overconsolidation?

f) Will any layer exhibit large and delayed settlements due to the construction of the embankment? In the affirmative case, identify the soil(s) in question and justify. Describe a procedure for preventing such behaviour.

g) In case of occurrence of a strong earthquake, may any of the soils exhibit deficient behaviour? In the affirmative case, identify the soil(s) in question and justify. Describe that behaviour and explain how it can be prevented.

h) Sketch the vertical evolution with depth of the undrained shear strength, c_u, of layer A along line X (in the tidal flat) and along line Y (in the riverbed) of Figure B1 before the placement of the fill. Indicate a plausible interval for the value of the undrained shear strength at point P of Figure B2, at 10 m depth.

i) Consider point Q located in layer D. Will the value of c_u at point Q be close to, lower than or larger than the value that would be obtained by extending the line drawn in the previous question to layer D? Justify.

j) Classify the four soils as to what concerns the expected dilatancy (positive or negative). How could you experimentally confirm your reply in the lab?

k) When will the safety relative to a rotational embankment and foundation soil failure be minimum: immediately after embankment construction or in the long term? Justify.

Solution Guidelines for Example 3

a) Based on the values of γ and γ_s, the void ratio, *e*, and the water content, *w*, can be obtained from $G_s w = S_r e$ and $\gamma = \gamma_s (1+w)/(1+e)$, where $G_s = \gamma_s/\gamma_w$ and $S_r = 100\%$ for all soil layers. The results are presented in columns 8 and 9 of Table B2.

Table B2. Results

Soil	γ_s (kN/m^3)	γ (kN/m^3)	e_{min}	e_{max}	w_L (%)	w_P (%)	e	w (%)	I_D (%)	I_C	A_t
1	26.0	18.5	0.25	0.95	-	-	0.86	33	13	-	-
2	25.8	20.5	0.36	0.89	-	-	0.50	19	74	-	-
3	26.3	15.0	-	-	88	40	2.18	81	-	0.15	1.20
4	26.1	20.9	-	-	53	22	0.47	18	-	1.13	0.56

b) Column 10 of Table B2 displays the values of the density index, I_D, for the granular soils 1 and 2, while column 11 presents those of the consistency index, I_C, for the clayey soils 3 and 4.

Soil 1 is very loose and soil 2 is dense. Soil 3 is very soft, while soil 4 is very stiff/hard.

Taking into account that the density and the consistency increase with the age of the deposit, it may be concluded that the more reasonable correspondence between the layers of Figures B1 and B2 and the soils of Tables B1 and B2 is:

- Layer A: soil 3, very soft silty clay;
- Layer B: soil 1, very loose sand;
- Layer C: soil 2, dense gravel;
- Layer D: soil 4, very stiff/hard clay.

c) Column 12 of Table B2 presents the values of the activity of clay, $A_t = I_P/(\%\ clay)$, which show that the clay fractions are not of the same type, with that of soil 3 being more active.

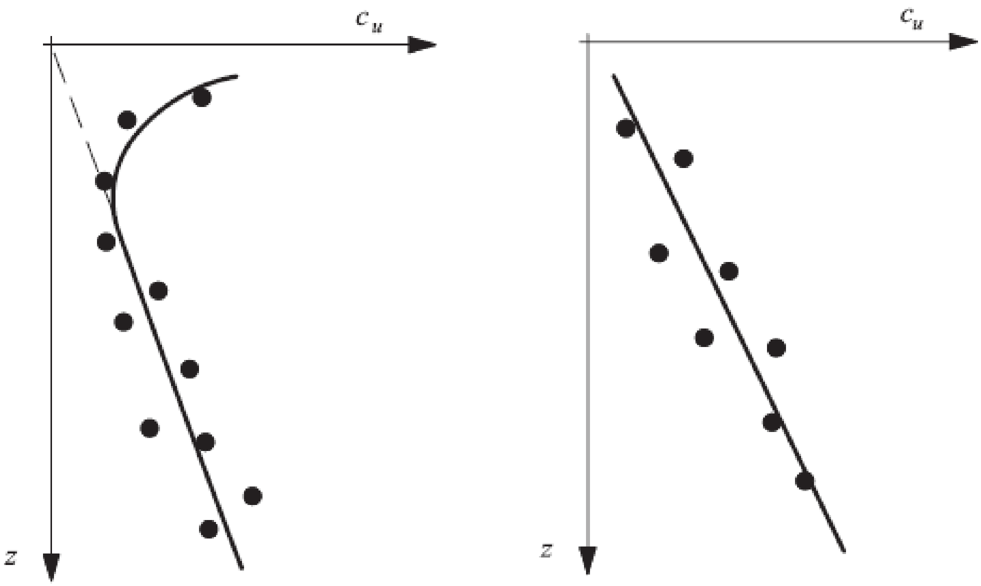
d) The finer the soil, the lower the permeability. So: $k_4 < k_3 < k_1 < k_2$.

e) Clay layer D, given its deep location in Figure B1 and its high consistency, may be highly overconsolidated. This prediction could be checked by performing oedometer tests on undisturbed samples. These would allow to estimate the maximum past vertical effective stress experienced by the soil. In case it significantly exceeds the at rest effective vertical stress, the prediction is confirmed.

f) Layer A, a very soft clay 15.0 m thick, may probably experience large and delayed settlement by consolidation. The consolidation rate can be significantly increased by means of a grid of vertical drains that reach sand layer B.

g) As B is a layer of very loose sand under the water table, two problems may occur: i) large settlement due to the vibration induced reduction of void ratio; ii) liquefaction, which may cause even more serious damage due to the dramatic reduction of soil strength. It would be appropriate to increase the density of the layer by vibro compaction.

h) Since layer A is a soft clay in this geologically very recent alluvial valley, it is very likely normally consolidated, with the undrained shear strength proportional to the at rest effective vertical stress, increasing linearly with depth. The difference between the (permanently submerged) riverbed and the tidal flat is that in the latter, due to the emersion-submersion cycles associated with the seasonal variations of the water table, a surface crust develops by desiccation whose undrained strength is higher. Figure B3 presents the evolution with depth of c_u in the two zones. The c_u/σ'_{v0} ratio lies typically within the [0.20, 0.40] interval. This interval is, in part, a consequence of the anisotropy of the undrained shear strength. Assuming the water level coincident with the ground surface, at point P, σ'_{v0} = 52 kPa. Therefore, a plausible interval for c_u is [10 kPa, 20 kPa].



(a) (b)

Figure B3. Evolution of c_u with depth: a) tidal flat (section X); b) riverbed (section Y)

i) Since layer D is probably overconsolidated, the undrained shear strength at point Q will be larger, or likely much larger, than the value obtained by simply extending the line drawn for layer A.

j) The soft clay and the loose sand will probably exhibit negative dilatancy (volume reduction), while the dense gravel and the very stiff/hard clay will probably experience positive dilatancy (volume increase). This could be confirmed by performing triaxial tests on undisturbed samples.

k) During the consolidation process subsequent to loading, the (positive) excess pore pressure dissipates, the average effective stress increases and the shearing stress remains practically constant. Therefore, the shear strength increases at each point of the clay layer A until the end of consolidation. This is why stability analyses must be carried out for the conditions prevailing at the end of construction, assuming undrained conditions.

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Authors' bios

Manuel Matos Fernandes, University of Porto, Portugal

Manuel Matos Fernandes is a full professor at the Faculty of Engineering of the University of Porto, where since the late 1980´s he has been responsible for research and teaching in Geotechnics. His main fields of research are numerical modelling of geotechnical structures, deep excavations and application of the limit state design approach to Geotechnics. For 15 years he was member of the committee responsible for Eurocode 7. He is author of two textbooks on Soil Mechanics and Geotechnical Engineering published in Portugal and in Brazil. In the last 10 years he has been responsible for teaching History of Civil Engineering to undergraduate students. In 2013 he was awarded the Pedagogical Excellency Prize at his faculty. He has a long experience as international consultant, particularly in bridge foundations and deep excavations. He is a member of ISSMGE TC306 Geoengineering Education. Since 2016 he is President of the Portuguese Geotechnical Society.

José Couto Marques, University of Porto, Portugal

José Couto Marques is associate professor (with tenure) at the Faculty of Engineering of the University of Porto and Coordinator of the Geotechnical Group, Department of Civil Engineering since July 2017. He holds MSc and PhD degrees respectively from University of Porto and University of Wales Swansea. In 1993-1994 he was a visiting scholar at Swansea. His research interests include (1) numerical modelling in geotechnical and structural engineering and (2) engineering education. He has over 120 papers published in international journals and conferences. He is Co-editor of Soils and Rocks, an International Journal jointly published by ABMS and SPG, the Brazilian and Portuguese Geotechnical Societies. He is also Joint Editor of iJEP, the International Journal of Engineering Pedagogy. He has served a 4-year term as Editor of Revista Geotecnia, jointly published by SPG, ABMS and SEMSIG (the Spanish Geotechnical Society). He is a Senior Member of the International Society for Engineering Pedagogy (IGIP) and belongs to IGIP's International Monitoring Committee.

"Student Centred Learning" Approach in the Development of Social Skills: Implementation in an Experimental Soil Mechanics Course

P. Kallioglou[1] & S. Vairamidou[2]

[1]*University of Thessaly, Volos, Greece*
kalliogl@uth.gr

[2]*Neapolis University, Paphos, Cyprus*
svairamidou@gmail.com

ABSTRACT: This paper presents the teaching framework of the "Experimental Soil Mechanics" course, which has been applied at the University of Thessaly (UTh) during the last five academic years and aims to combine the acquisition of scientific knowledge with the development of social skills of students. The latter reflects the needs of post-modern societies, induced by high competition and changing conditions derived from globalisation. For this purpose, the "Student Centred Learning" (SCL) approach has been adopted by means of various teaching techniques: questionnaires, diagnostic assessment, dialog, experiential learning, laboratory experiments, individual work and team work, oral presentation, writing technical reports, role playing, formative evaluation and differentiated teaching. The benefits of SCL to the knowledge targets of the course were direct; however only a qualitative evaluation on the development of skills of students was possible, based mainly on the formative evaluation conducted every week after the completion of the lesson and the hetero-evaluation among students. The results show that the SCL approach provides an effective learning environment for the development of the social skills of students, e.g. communication, initiative, responsibility, collaboration, critical thinking, adaptability, self-confidence, tolerance, leadership.

Keywords: social skills, student centred learning approach, experimental soil mechanics

1 Introduction

In the history of education research worldwide, the connection of teaching practice with learning theories was initially focused on the subject-based teaching and learning approach, which comprises three questions: What - how - why a certain content of a subject is taught? The evaluation of the results of this approach is quite easy, as it is related only to the level of students' knowledge in a given subject.

Then, a new concept transferring the interest from teacher centred to student centred learning (SCL) approach was developed, as a result of the social conditions improvement. The European Standards and Guidelines for Quality Assurance in Higher Education (ESG, 2015) present the SCL approach to institution programmes in a way that encourages students to take an active role in creating the learning process. However, due to the fact that: (a) the recognition of benefits of the implementation of SCL or other modern educational approaches in teaching practice of Higher Education are not widely known by the academic community, and also (b) many academic teachers are not familiar with learning theories, the evolution in teaching procedure is mostly based on teachers' personal experience and therefore the quality of teaching practice and results remains uneven (Kind, 2009). More recently, Case (2019) has advocated for reconciling the two approaches (teacher centred and student centred) and she also highlighted the significance of the scientific knowledge in the engineering classrooms, in the sense that the curriculum should be taught with the simultaneous students' engagement with it.

In this paper, the design and the main findings of the implementation of the SCL approach in the “Experimental Soil Mechanics” course, taught in the context of the five-year undergraduate study programme of the Civil Engineering Department of UTh, are presented and discussed, with emphasis in the development of social skills of students. The authors jointly developed the SCL approach and then the first author applied it to her course at UTh.

2 The “Student Centred Learning” (SCL) approach

The term “student centred learning” (SCL) has been widely used in literature and is linked to a range of related perspectives, such as flexible learning, experiential learning, self-regulated learning etc. (Damşa & de Lange, 2019). Historically, SCL has been credited to Hayward as early as 1905 and later to Dewey’s work (1956), but it was Carl Rogers, in the 1980s, with whom the SCL concept was expanded into a learning approach (ESU, 2010). The SCL approach is broadly based on constructivist learning theory, which is built on the idea that knowledge is not acquired by the students, but constructed based on their personal experiences and learning environment. Students bring past experiences and cultural factors to the learning environment and thus each of them has a different interpretation and construction of the knowledge process. The following definition of SCL in Higher Education is given by ESU (2010):

“*Student - Centred Learning represents both a mindset and a culture within a given higher education institution and is a learning approach which is broadly related to, and supported by, constructivist theories of learning. It is characterized by innovative methods of teaching which aim to promote learning in communication with teachers and other learners and which take students seriously as active participants in their own learning, fostering transferable skills such as problem-solving, critical thinking and reflective thinking.*”

Over the last decade, the concept of SCL has gained political recognition on the European level, as well as in national plans for higher education and institutional strategies, e.g. Bologna Process agreements (EHEA, 2009).

3 Social Dimension of Education Procedure – Social Skills in the SCL approach

As mentioned above, the education procedure in the SCL approach is determined by both the teacher and the students, who bring their personal experiences and culture, as well as the learning environment, which reflects the contemporary social conditions. In this context, teaching practice is formed as a continuous negotiation between the teacher and students, during which the learning environment evolves according to the evaluation of the teaching procedure, e.g. more team projects are assigned to students after the detection of cooperation problems among them in the classroom (Papamichail, 1988). The social dimension of education procedure is reflected in the above features, as well as in the simultaneous development of social skills of students. The latter corresponds to the needs of post-modern societies, induced by high competition and changing conditions derived from globalisation, facts that require employees with initiative, creativity and teamwork attitude (Goleman, 1999).

The importance of social skills has been officially recognized by the European Commission (1995) in the White Paper on Education and Training, in which the need for the combination of fundamental knowledge and technical knowledge with social skills is underlined. The latter concerns interpersonal skills, e.g. behaviour at work, and a whole range of skills corresponding to the level of responsibility held, such as the ability to cooperate and work as part of a team, creativeness and the quest for quality. The Lisbon Summit (2000) - in which the strategy for the economic growth of EU country members was presented - introduced the concept of “new basic skills”, which includes social skills of employees, as a basic requirement for the economic development, with more and better jobs and mostly greater social cohesion. In this context, social skills include self-confidence, self-direction and risk-taking. Moreover, individuals should be able to adapt to changes, new challenges and situations, as well as learn and acquire new skills rapidly (Commission of the European Communities, 2000).

4 The SCL Approach in the "Experimental Soil Mechanics" course

4.1 The teaching framework

As mentioned previously, the teaching practice of the SCL approach is not limited to a certain methodology, but involves various techniques forming the teaching framework of any scientific subject, adapted to students' experiences and needs, towards the development of their social skills. Thus, the teaching framework is initially introduced in the curriculum of the course and gradually reconstructed, changed or abandoned in the interactive teaching environment (Clark & Peterson, 1986).

In this paper, the teaching framework of the "Experimental Soil Mechanics" course is presented. It is a 5 ECTS (European Credit Transfer and Accumulation System), seventh semester, undergraduate, mandatory course offered to students of the Civil Engineering Department who choose the Geotechnical and Geoenvironmental Engineering Division. A full-time student needs to complete 30 ECTS per semester. The maximum number of students attending the course during the last five academic years is 25. The course is designed and coordinated by the teacher. There are no teaching assistants or technicians supporting the teaching procedure. According to the authors' opinion, 25 is the upper limit of students who can actively participate in performing experiments, in the context of the SCL approach, when the course is coordinated by one teacher. The students have not been exposed to the SCL approach in previous courses in the Department.

The teaching framework consists of three levels:

(a) the course is organised in fourteen lessons with four hours duration, and the learning goals are stated. The teaching model used is based on the four pillars of education proposed by UNESCO (Delors et al., 1996; Delors, 2013), which are inextricably linked:
(i) learning to know, (ii) learning to do, (iii) learning to live together, and (iv) learning to be. "Learning to know" develops a thirst for knowledge in students and a desire to gain better understanding of things and situations already known or changed. "Learning to do" nowadays means that students develop skills in order to be self-confident and able to deal with the various challenges of working life. "Learning to live together" focuses on the skills like understanding, tolerance and living harmoniously with others. "Learning to be" concerns self-knowledge, which is the most difficult among the four pillars, and aims to develop creative potential of individuals.

(b) the roles of teacher and students are activated and the learning goals are communicated. The teaching and learning process is implemented by various teaching techniques, in which the teacher acts as a guide and a facilitator and the students are active participants in their own learning (they perform - not watch - laboratory tests). The latter aims to develop their social skills, e.g. communication, initiative, responsibility, teamwork attitude, critical thinking, adaptability, self-confidence, tolerance, as well as other skills, such as writing technical reports and making oral presentations.

(c) the assessment of the teaching and learning process and of the learning goals is performed at the end of each lesson and is used as a feedback for the next lesson. This type of assessment is defined as formative assessment and is used to provide on-going feedback that can be used to improve the educational process while it is happening. The presentation given by each student team after conducting an experiment is evaluated by the other teams of students (hetero-evaluation). A final evaluation of the course, the teacher and the facilities is performed by the students at the end of the semester, providing useful information for the improvement of teaching procedure for the next year, as well as for the studies programme of the Department.

4.2 The content of the "Experimental Soil Mechanics" course

The course introduces the students to the experimental tests used for the assessment of physical and mechanical soil properties, which determine the soil behaviour in technical works. It includes two parts: (a) laboratory tests (eleven lessons) and (b) insitu tests (three lessons), as shown in Table 1. The course offers the opportunity to students for a deeper understanding of the basic concepts related to mechanical soil behaviour (e.g. undrained shear strength), which have been taught earlier in the context of "Soil Mechanics" course.

The need for reducing the content of Geotechnical Engineering courses has been stated since 1991 (Orr, 1991): "*More is not better, better is better. Indeed less might be better when planning courses".*

Table 1. List of tests included in the "Experimental Soil Mechanics" course

Test	Soil parameters	Soils
Diagnostic exercises performed by the students for the identification / description of	colour, size and shape of soil grains, water content, soil structure, organic matter and soil strength	15 natural soils (gravelly, sandy and clayey soil samples stored in the laboratory in dry condition) The soil specimens used are artificially prepared in either dry or wet condition
Laboratory soil tests performed by the students for the determination of	water content [1] density [1] specific gravity grading curve (sieving and hydrometer tests) organic content calcareous content Atterberg limits (LL, PL, SL) undrained shear strength (unconfined compression test) [1] compressibility parameters (one-dimensional incremental loading test) [1]	Natural clayey soil (samples provided to the Department every year by a geotechnical engineering company, after teacher's request) The samples are covered with paraffin, enclosed in plastic bag and stored in the laboratory [1] specimens from boreholes
	specific gravity [2] grading curve (sieving tests) [2, 3] coefficient of permeability (constant head permeability test) [2] minimum density [2] compaction curve (Proctor test) [2] strength parameters (direct shear tests CD) [2]	Natural sandy soils (NP) (stored in the laboratory in dry conditions) [2] uniform clean sand (NP) [3] well graded clean sand (NP)
Laboratory soil tests performed by the teacher and demonstrated to the students for the determination of	strength parameters (triaxial compression tests CD) [2] (The data records are given to the students for the determination of strength parameters)	Natural sandy soils (NP) (stored in the laboratory in dry condition) [2] uniform clean sand (NP)
Insitu tests presented virtually in the classroom by the teacher (by means of videos). In situ technical visits of students for watching SPT and/or Plate test. Exercises are given to the students for the evaluation of	D_r, φ', c_u, E, G, V_s etc. based on the results of: SPT CPT Plate load test PMT (pressuremeter test) Vane test Geophysical seismic tests	

The shift to basic concepts and important technical subjects, which should define the content of instruction, also with references to the recent research achievements in the scientific field, is described in the "KISS method: Keep It Simple Stupid!" (Graham & Shields, 1988). In this logic, and adopting Graham's point of view that "*the process and excitement of learning are important, not the facts themselves*", the content of the "Experimental Soil Mechanics" course is limited to the classical and conventional soil mechanics tests, that are mostly performed in geotechnical practice, but also with some references to modern experimental methods.

4.3 The learning goal and targets of the course

The learning goal of the course is that students acquire the knowledge: (a) to choose the appropriate soil mechanics' tests among a variety of experimental methods, and also (b) to perform these experiments, in the case of laboratory tests, in the context of planning and conducting a geotechnical investigation for a technical project, as well as (c) to evaluate the results of a geotechnical investigation. The purpose of the geotechnical investigation is the determination of the design values of soil parameters needed for the geotechnical study of technical projects.

The learning goal is analysed - based on the four pillars of education proposed by UNESCO - to the following targets, which foster the social skills development of students:

(i) learning to know: the students acquire the knowledge to
- identify the physical and mechanical parameters required for the determination of soil behaviour in technical projects.
- describe the experimental methods for the determination of the above parameters.

(ii) learning to do: the students learn to act and investigate for
- the suggestion of the most appropriate experimental methods and testing equipment used for the determination of geotechnical parameters.
- the design of a testing programme of a geotechnical investigation, based on the type and the requirements of the technical project.
- the writing and evaluation of the technical reports presenting the results of the testing programme and the geotechnical parameters derived.

(iii) learning to live together: the students communicate and accept their colleagues in order to
- work together as members of a team under the supervision and the guidance of a student - leader for fast results and high productivity, and simultaneous development of communication, comprehension, tolerance, collaboration, responsibility and organisational skills.
- work together as members of a team for the oral presentation of their test results and technical reports to the other teams. The evaluation of the reviews made by the other teams is used to improve their learning process and their judgement.
- participate in teams who work together for the correction of their test results and their compilation into a common technical report.

(iv) learning to be: the students transfer their knowledge to the real world
- by performing a self-evaluation based on the learning process, e.g. recognition of the importance of knowledge acquired, difficulties during the learning process etc.
- by participating in a role game. The students play the role of professional geotechnical engineers, who design and conduct an experimental soil mechanics testing programme and also write the technical report, which is used for the design of a technical project (Eurocode 7).

4.4 The teaching techniques, activities and formative evaluation

Several teachers of Geotechnical Engineering science support the aspect that the course of "Experimental Soil Mechanics" can and should be taught virtually, as these tests require considerable teaching time, and also because the main goal of the course is not the knowledge of performing the tests but rather the design of a testing programme and the evaluation of the experimental data derived. The large number of students, the lack of experimental infrastructure, scientific and technical staff, as well as the limited time available are factors that reinforce this point of view. On the other hand, the teaching in an experimental laboratory offers the students real experience and opportunities for active participation. The students are not observers but protagonists in the education procedure. They acquire knowledge and perceive concepts through experiential learning using their mind, body and senses, and they can alternate focus between theory and practice, developing in this way the transfer of knowledge to a simulation of real life.

The applied teaching techniques and the types of supporting teaching and learning activities of the "Experimental Soil Mechanics" course are the following: questionnaires, diagnostic assessment, dialog, experiential learning, laboratory experiments, individual work and team work, presentation, writing reports, role playing, formative evaluation and differentiated teaching. Differentiated teaching is recognised as a means to meet the individual needs of all students, who bring – as mentioned above – their past experiences and cultural factors to the learning environment, and thus each of them has a different interpretation and construction of the knowledge process. For students with learning difficulties, differentiated teaching provides alternative learning pathways. In this framework, the teacher has mainly the role of a guide; she initially provides the students with the basic knowledge for the experiments (describing experiments through slides, photographs, videos and step-by-step instructions), and then her role changes to that of a coordinator. The students, on the other hand, are active participants in their own learning (they perform - not watch - laboratory tests) and develop social skills (communication, initiative, responsibility, comprehension, teamwork attitude, critical thinking, adaptability and organisational skills).

For the implementation of differentiated teaching in the course, in the beginning of the semester (first lesson) the students fill out a questionnaire with some personal information and their learning preferences and difficulties. The questionnaire includes: their name, age, marital status, place of origin, diplomas and foreign language certificates, professional experience and work status, technology and social media use, personal interests, interests in their studies in the Department, preference between theory and laboratory exercises, preference between individual and team work, expectations and learning goals of the course, and learning difficulties (e.g. dyslexia, visual or hearing difficulties). The questionnaire information is confidential and helps the teacher in organizing the lessons in a way that all students are involved in the educational process. As a result, a variety of learning activities (individual or team works involving the performance of experiments, the calculation of results, the analysis of the data and the writing and presentation of technical reports) are offered to the students. The questionnaire information is very useful especially in the formation of the working teams, which must consist of students with different abilities / disabilities, gender, social background and culture (criteria of students' team formation).

At the first lesson of the course, a diagnostic assessment of the students' knowledge level takes place by means of a diagnostic exercise, which includes the identification / description of a number of soils given to the students, having different composition, soil structure, moisture content and shear strength (Table 1). In this exercise, the students do not conduct experiments but use only basic tools (vernier, magnifying glass, charts for the visual evaluation of size, roundness and sphericity of soil grains), their senses (vision, smell and touch), and their pre-existing knowledge and past experience for the soils' description, in terms of: colour, size and shape of soil grains, water content, soil structure, organic matter and strength. The soil strength can be described (soft, stiff or hard soil) with the use of thumb, thumb nail or finger. A similar exercise, which however included the conduction of soil mechanics tests by the students without having first attended the lectures, has been presented by Hachich (2012). The results of the exercise presented herein reveal the capability (or not) of students to understand the descriptions of soil types given in books or presented in the classroom in previous courses. Most of the students exhibit insecurity and difficulty in describing the soils, but the teacher instead of discussing their performance or presenting the right answers in the classroom, gives the same exercise to the students again by the end of the semester. As shown in Figure 1, where the average results of the diagnostic exercises are presented, at the first lesson the students exhibit difficulties in identifying (among others) the presence of water in soils (53% of students detect water in dry soil samples) and the type of soil grains (76% of students describe the pieces of a dry clayey sample as gravel grains).The first exercise allows the formative feedback of the course and is very useful to the teacher, whereas the second exercise is a useful tool for the self-evaluation of students, who appreciate the knowledge gained and develop critical thinking. For this purpose, an oral presentation of the comparison between the results of the two experiments is given by each student in the class.

At every lesson in laboratory testing, the students have to perform a soil experiment. Initially the teacher presents the methodology, the testing procedure and the expected test results. Then, the students are invited to conduct the test (on their own or in teams) under their teacher's supervision. Natural soil samples are used for the tests, which are retrieved from boreholes for the site investigation of technical projects. In this way, the students understand the importance of the knowledge they acquire during the lessons and the connection with geotechnical practice. After each lesson, the students have to process the data, calculate the results and write a technical report (which describes the testing procedure, the results obtained and the evaluation of the parameters estimated).

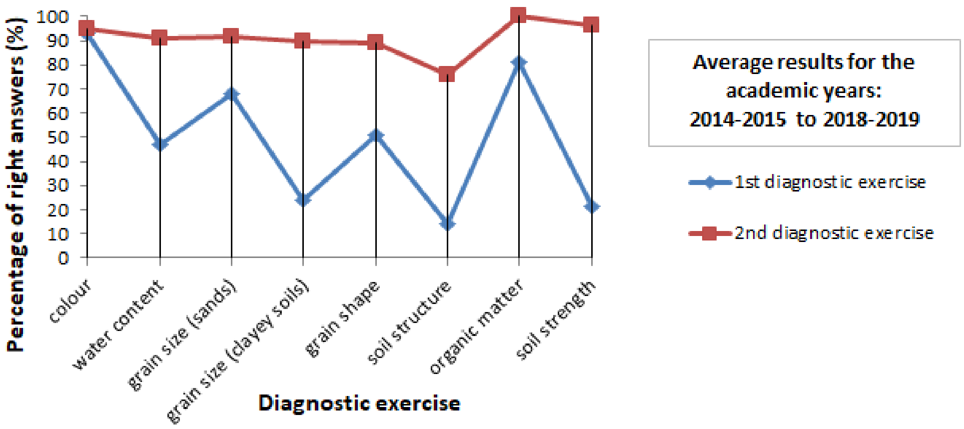

Figure 1. Results of the diagnostic exercise

Detailed instructions for the technical report are given to the students, who work together without supervision in order to deliver the report to the teacher at the next lesson and present it to their classmates. All the classes during the last five years have expressed their enthusiasm for the presentation activity as students have not had the opportunity to practice in it many times before. The evaluation of the presentations is made by the other students or teams (hetero-evaluation). The evaluation is based on the following criteria: content and organization, speakers' comfort, clarity of figures and overall presentation, using a grading scale from 1 (weak) to 5 (strong), and is followed by a discussion. During the discussion, the students accept the others' opinion. It is also observed that what impressed the students-evaluators from the presentations of the other students, are incorporated in their subsequent presentations. Figure 2 presents indicative evaluation results of presentations and reports. There is an improvement in student performance in presentations and reports as the course progresses and, hence, in the associated skills (collaboration, communication, self-confidence). The fact that the results of the hetero-evaluation follow the same trend as the presentations' evaluation made by the teacher shows that the students exhibit responsibility.

The assignment of experiments to individuals or teams of students is made by the teacher. In the first experiments, due to their simplicity and short duration, there are no teams and each student performs the tests alone. This front-line teaching is very useful in the beginning of the semester for the detection of any students' learning difficulties. In subsequent lessons, when the students become more familiar with the laboratory environment and equipment, they are assigned to perform more complex experiments in small groups of two to five people. The composition of the teams is not constant in all experiments, but varies. At the first experiment it is the students' decision, which ends up systematically in only-boys and only-girls teams. Then, the teacher based on the information of the questionnaire and the criteria mentioned above decides on the composition of the teams, which is changed in every lesson, so that every student will have the opportunity to cooperate with the maximum number of the other students. The teacher includes in every team a student with preference for teamwork, according to the questionnaire information, which usually acts as the team leader. The usual students' reaction to the team changes is initially negative; they react to the change and the unknown and insist to form teams only with their friends (usually students from the same place of origin). Nevertheless, this learning environment prepares the students for the challenges they are going to meet later on their professional work and also fosters their skills of communication, collaboration, self-confidence and leadership.

During the lessons on field testing, one or two educational visits are planned for the students to watch insitu geotechnical experiments and investigations. The students are invited to keep notes for the testing procedure in the field, which they have to deliver to the teacher at the end of the visit. In this way, the attention of the students is achieved.

Upon completion of every lesson, the students proceed to a formative evaluation by answering the following questions: (a) what is the most important thing you have learned today, (b) what did you do easily, (c) what was difficult for you, (d) what do you propose to do in order to overcome your difficulty, and (e) what is the implementation in practice of the things you have learned today. This evaluation helps the students to sum up the benefits of the learning process and also contributes to the formative assessment of each lesson.

By the end of the semester, when the students' knowledge and experience in laboratory tests is adequate, they are assigned by a technical company to conduct a laboratory testing programme for

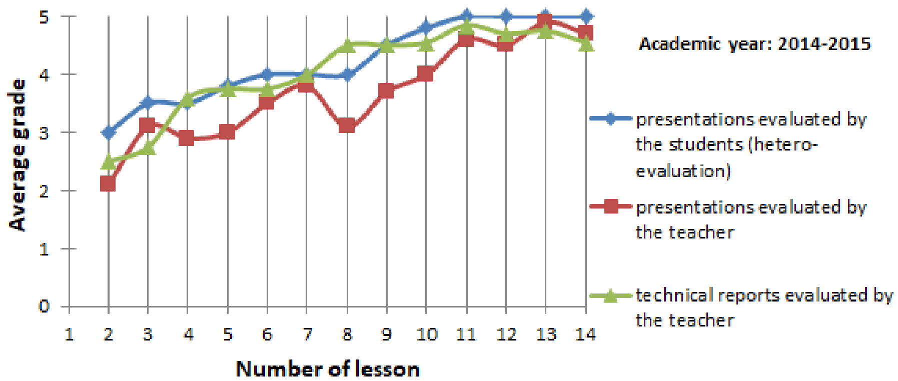

Figure 2. Results of the evaluation of presentations and technical reports

the geotechnical study of a technical project. The communication for the assigned study is live and usually done via skype chat, during which the company representative describes the project and asks the students to play the role of the engineer, who will design and conduct the testing programme on soil samples from the project site. Students must submit the technical report to their "client" with the results of the tests and their evaluation within a specified time. With this role playing game, the students have the opportunity to cultivate their responsibility, self-confidence, critical judgment, communication and organisational skills. The report is reviewed by the company and returned to the students. Although the evaluation of this report does not contribute to the final mark on the course, the students participate in it with enthusiasm and responsibility.

4.5 The overall evaluation of the education procedure and discussion

The benefits of the diagnostic tests conducted in the first lesson and by the end of the semester, the formative evaluation in every lesson, the hetero-evaluation of the presentations among the teams of students and the evaluation on the project assigned by the technical company were presented in the previous section, since they are inextricably linked to the evolution of education procedure. Their results are used by (a) the teacher, to improve the teaching techniques while the course is ongoing, so that all students are active participants of it, and (b) the students, to assess their knowledge level and progress, identify their abilities and weaknesses, and improve the learning process.

An evaluation at the end of the semester (final evaluation) is also conducted, using the course evaluation system of the Department and by means of a questionnaire. The questionnaire consists of 25 questions, using a scale from 1(low) to 5(high) with space available for comments. The questions are grouped as following for the evaluation of: (a) the course, (b) the teacher, (c) the assistant staff, (d) the laboratory infrastructure, and (e) the student. The results are made accessible to the teacher no earlier than two months after the completion of the semester and are used by the teacher to improve the education procedure of the course for the next academic year. The number of the students that participate in this evaluation is generally low for all courses. In the case of the “Experimental Soil Mechanics” course the participation is also lower (50% approximately) compared to the formative evaluation, because - as the student state - it does not give a feedback to, or can affect, their learning environment, and also because they find the number of questions big. Nevertheless, based on the results of the final evaluation for the last five academic years, (a) the students’ perception on the way that the course is organised, the teacher and themselves is reflected on the value of 4.2/5.0, 4.2/5.0 and 4.4/5.0 respectively, and (b) 14% of the students consider that the writing of the technical reports is a very time consuming activity and should contribute more in their final mark on the course.

At this point, it must be mentioned that the learning goals of the course are communicated to the students in the first lesson, so it is clear to them that the knowledge targets are combined with the development of various social skills. However, whereas the assessment on the knowledge targets’ achievement is easy, the evaluation of the social skills is mainly qualitative in the context of this course. This is because, the social skills are not included in the final evaluation and also in the formative evaluation there are only text answers (without scale grade). For this reason, the general picture of the students participating in the learning activities and the communication level among them and also with the teacher during the lessons is used for the evaluation of the social skills development.

The main findings of the five years implementation of SCL approach to the course are presented below:

The students express their satisfaction for the transparency in the learning goals and the power given to influence their own learning experience.

The diagnostic exercise corresponds to the learning targets (i - learning to know) and (iv – learning to be). The results of the first test show the students’ weaknesses to answer right, as approximately only 50% of the given answers are right. This percentage is significantly increased to 90-100% in the second test, showing that the education procedure gives the students the opportunity to mature as learners. The diagnostic test is followed by a formative evaluation, which shows that the students identify their initial difficulties and the progress achieved later. This self-evaluation of students is a useful tool for the development of their self-confidence. As mentioned previously (CEC, 2000: Lisbon Summit), self-confidence is a social skill which reinforces the social cohesion.

Based on the answers given in the formative evaluations taking place at the end of every lesson, it is shown that, in the framework of the learning activities performed in this course, the students:

(a) successfully participate in the experiential learning activities, in order to acquire the knowledge subject of the course (learning target ii – learning to do). 90% of the students understand the importance of the lessons and 85% find the experimental procedures easy (questions a, b and e of the formative evaluation).

(b) develop social skills like communication, negotiation, collaboration, responsibility, efficiency etc. (learning target iii – learning to live together). In the SCL approach the learning procedure is a social experience. Although almost 50% of the students are negative to the composition of the working teams (question c of the formative evaluation), they act with responsibility, exhibit adaptability to changes and tolerance to each other, realise that first of all they are part of a team, and therefore conduct the experiments with success, write the technical reports and make the presentations.

(c) engage actively with the domain knowledge and practices (learning target iv – learning to be). 70% of the students can see the implementation of the knowledge in practice (question e), and 15% who face difficulties during the experimental procedure (question c), writing or presentation, exhibit self-confidence to overcome their difficulties with more practice and work (question d).

The hetero-evaluation of the presentations among student teams shows that students act with responsibility, and make their review with critical thinking and judgment (learning targets iii & iv), by applying specific evaluation criteria, accepting others' opinion and adopting new ideas from others' presentation to their own presentations.

The evaluation on the project assigned by the technical company shows that the students exhibit a variety of social skills e.g. communication skills, teamwork attitude, responsibility, organizational skills, self-confidence (learning targets ii, iii & iv) through the collaboration within the working team and the company as well.

The final evaluation provides an indication of students' perception on the course, but there is no assessment on the development of social skills of students. Nevertheless, the students' perception of the way that the course is organised is very good.

In addition to the formative evaluation, hetero-evaluation and project evaluation, a qualitative assessment of the development of social skills of students is made by the teacher based on the conversations with the students and the observation of students' classroom behaviour (learning targets iii & iv). The general picture - which is improved during the course - is that the students exhibit high responsibility and enthusiasm during the experiments and role playing game, communicate easily, do not complain for the time spent on homework, see the implementation of knowledge in practice, try to overcome the difficulties, behave with respect to their colleagues, deliver all the projects assigned and exhibit a teamwork attitude even with persons they don't like.

5 Conclusions

In the context of the "Experimental Soil Mechanics" course, the SCL approach provides an effective learning environment for the development of social skills of students, as the teaching and learning procedure itself is a social experience. For the implementation of the SCL approach, a variety of teaching techniques is used in order to activate the role of students in the learning procedure.

The main conclusions of this study are presented below:

The number of twenty five students, who can participate effectively in the SCL approach under the guidance of one teacher, is considered the upper limit. For larger classes, a number of teaching assistants should be involved.

Diagnostic exercises followed by formative evaluation are considered as a useful tool for the development of self-confidence and self-knowledge of students.

The experiential learning and the role playing game are the most favourable learning activities of the students. The least favourable is the cooperative working within teams of persons they are not fond of.

An assessment of the development of social skills of students is possible and is mainly based on the hetero-evaluation, the formative evaluation of every lesson, as well as the general behaviour which the students have in the laboratory. This assessment shows that the students develop a variety of social skills, among which are the communication skills, teamwork attitude, responsibility, organizational skills and self-confidence.

Since the benefits of the SCL approach in social skills development are not generally measured or automatically identifiable, an evaluation performed with former students - who have participated in SCL approach and now are professional geotechnical engineers - is suggested.

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Authors' bios

Polyxeni Kallioglou, University of Thessaly, Greece

Dr. Polyxeni Kallioglou is a lecturer at the University of Thessaly, Greece, who specialises in the field of geotechnical engineering. She graduated in civil engineering from Aristotle University of Thessaloniki, Greece, and obtained a Ph.D. at the same university. She is a member of ISSMGE. Her disciplinary research interests involve advanced soil mechanics and soil dynamics laboratory testing and seismic performance of civil engineering structures including quay walls and wind turbines. Her primary focus is on the dynamic behaviour of natural soils, cemented soils, organic soils and liquefiable soils, as well as on soil improvement methods. During the last decade, Dr. Kallioglou has been involved in research in engineering education at several higher education institutions in Greece, and particularly in the student-centred learning approach.

Syrmo Vairamidou, University of Pafos, Cyprus

Dr. Syrmo Vairamidou is a collaborator at the University of Pafos, Cyprus. She graduated in pedagogy and theology from Aristotle University of Thessaloniki, Greece, and obtained a Ph.D. in sociology at National and Kapodistrian University of Athens, Greece. During the period 1998-2018, she served as a consultant to public and private education sector for the Greek Ministry of Education and Religious Affairs. During the period 2008-2014, she was the director of the 1st Regional Training Centre of Thessaloniki, Greece, under the Ministry of Education and Religious Affairs, implementing training programs for the educators of primary and secondary schools. For the last fifteen years, she has been teaching humanitarian and social subjects at several institutions of higher education in Greece and Cyprus, by applying modern teaching methods towards the development of students' social skills and abilities.

Laboratory Experiments in Soil Mechanics by Means of Digital Twins and Low-Cost Equipment

A. Ledesma, P.C. Prat, A. Lloret, R. Chacón & M. Sondon

Universitat Politècnica de Catalunya - Barcelona-Tech. Barcelona, Spain
alberto.ledesma@upc.edu, pere.prat@upc.edu, antonio.lloret@upc.edu, rolando.chacon@upc.edu, mercedes.sondon@upc.edu

ABSTRACT: The Soil Mechanics Laboratory has been traditionally an important component in most courses on Soil Mechanics and Geotechnical Engineering. Nowadays, the available technology allows to build low cost systems that bring the experiment to the student in a simple manner. The paper describes two examples including a physical model of a falling head permeameter and a simple device to perform direct shear tests. Students can be directly involved in the development of these pieces of equipment, so they become familiar with a technology that is simple and available at low cost. Simplifying and decreasing the cost of educational experiments puts at the grasp of students concepts of monitoring, automation, digitalisation and real applications and eventually unites theory and practice. This integration of knowledge is a fundamental aspect in the future development of Internet of Things and Construction 4.0.

Keywords: Laboratory, digital twins, low-cost equipment

1 Introduction

To some extent Soil Mechanics and Geotechnical Engineering is a subject with two souls. One is based on rigorous scientific postulates, developing concepts by means of theoretical assumptions. The other one is based on empiricism and practical applications to real construction problems. Both approaches coexist and an important effort is required by University lecturers and professors to maintain a link between these two souls. Although this difficulty may be present in many subjects within the Civil Engineering Curriculum, it is in Geotechnical Engineering where this duality becomes more evident. This is probably because Soil Mechanics is a relatively young subject and theories are less developed than in Structural Engineering or Hydraulics. Also, the nature of soil complicates any rational analysis based on simple mathematical descriptions. As a consequence of that, the gap between theory and practice seems to be more important than in other disciplines.

Apart from this difficulty, local tradition plays an important role when weighting the percentage of theory and practice in the curriculum. This is a well-documented fact within all branches of Engineering. In some countries, engineering colleges are strongly “science-oriented” shifting away from practice in a process sometimes referred as “academic drift” (Harwood, 2006). This is particularly evident in continental Europe as an outcome of the rationalist tradition. However, in other countries (i.e., Britain, USA), empiricism has been an important point when defining the engineering curriculum. In that case experimentation plays an important role and many concepts are first introduced to students by performing a simple experiment in the classroom (Feisel and Rosa, 2005).

When teaching Soil Mechanics and Geotechnical Engineering it is possible to adopt either one framework (scientific or practice oriented), but in all cases laboratory experiments are carried out or at least described (Jaksa, 2008). The importance assigned to the laboratory work depends not only on the local tradition, but also on the resources available, number of students, etc., as maintaining a laboratory is always expensive even for teaching purposes. The development of virtual labs (e.g. Jaksa et al., 2016) has contributed to the reduction of operational costs, but still classical, real (not virtual) experiments are useful when introducing new concepts to students. Now the technology available has considerably reduced the cost of producing laboratory equipment and a new opportunity for teaching a subject based on experimentation arises.

The paper presents two experiments developed in this context. The first example refers to a falling head permeameter to measure permeability of sandy soils. A simple device was used to perform the experiment using low-cost sensors. From measurements of the level of water at the inlet and the time, it is possible to estimate soil permeability. Using visual digital tools it is possible to represent the experiment in a digital model, so a view of the test including the falling level of water and a real-time analysis of measurements can be presented. This is called a digital twin, that is, a digital replica of a physical model whose behaviour can be observed simultaneously (digitally and physically) in real time. The second example refers to the construction of a direct shear test apparatus using low-cost sensors and a 3D printer. In this case the objective was to replicate a conventional direct shear equipment, appropriate for teaching purposes. The technology available is also useful when developing research-oriented equipment (Pierce, 2012). The quality of the sensors and of the elements manufactured with a 3D printer has improved significantly and these techniques are already being used in research laboratories. This paper points out the new paradigm that this technology provides to Geotechnical Engineering students.

2 Open-source laboratory

The term “open-source” refers usually to a software that is both free and available in source code. “Free” in this context refers to freedom to manipulate, redistribute or modify the code, but does not necessarily mean free of charge. This term has been now extended to hardware (Pierce, 2014), and refers to a hardware whose design is made publicly available and anyone can modify and improve.

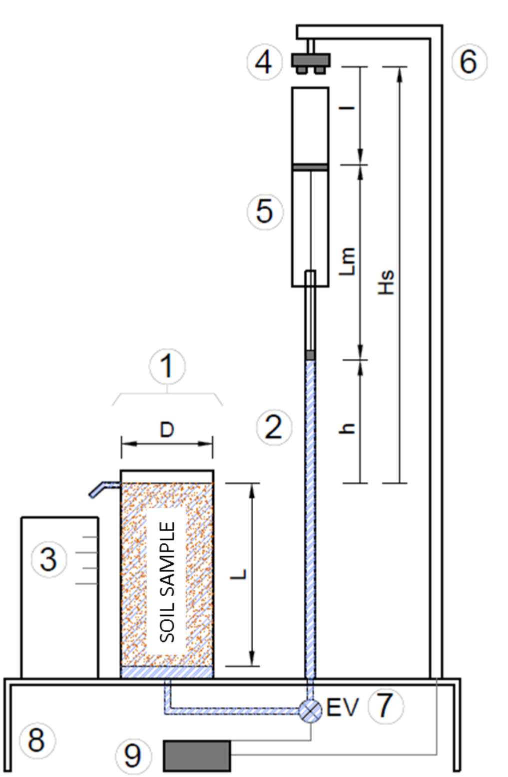
There are a few ingredients involved in this concept. On the one hand, 3D printer technology allows materialising parts of devices by additive manufacturing from a variety of materials. On the other hand, an Arduino microcontroller constitutes the brain of the system. This microcontroller is powerful and easy-to-use open hardware-prototyping platform for students with little to none prior knowledge in electronics. In addition to that, low-cost sensors are used to measure the physical variables in the experiment. Finally, to replicate the model in a digital manner, a graphical user interface can also be developed as part of the system.

There are several examples of application of this technique to Civil Engineering Education (Chacón et al., 2018) including models that are totally developed by students from scratch. The experience of the authors suggests that digital twins can be very useful for the understanding of physical phenomena either in a portable form at the classroom or in the laboratory. In addition to that, students become familiar with sensors and microcontrollers, which is a positive side effect, as most civil engineering students do not know these techniques. Thus, measuring physical variables and interpreting real problems becomes affordable not only in the laboratory, but also when working in practical applications in their future careers.

3 A falling-head permeameter

The methodology outlined above was adopted to build a piece of equipment to measure permeability in sandy and silty soils. This test requires the design of a soil column through which water flows for a period of time. The liquid stored in a tank percolates and its height is continuously measured with distance sensors and subsequently shown in real time digitally. The solid parts (supports, etc.) have been designed with impervious 3D printed materials.

Figure 1 presents a sketch of the physical model and Figure 2 shows the digital model fed with the data provided by the Arduino microcontroller UNO board, i.e. a basic board. The digital model developed using a graphical user interface allows to interpret the experiment directly in real time conditions. In this case, the combination of the physical and the digital models helps the student to understand concepts.



1	Soil sample
2	Burette
3	Beaker for water exit
4	Ultrasonic sensor to measure distance
5	Reflection plate floating on the burette water
6	Solid support
7	Solenoid valve, connected to microcontroller
8	Supporting base
9	Arduino microcontroller

Figure 1. Physical model of a falling head permeameter, controlled by an Arduino UNO board (L = sample height, D = sample diameter, Hs = distance sensor - top of sample, Lm = Length of bar connecting the reflection plate and the floating device in the burette, h = distance between burette water level and outlet water level, l = distance from the sensor to the reflection plate)

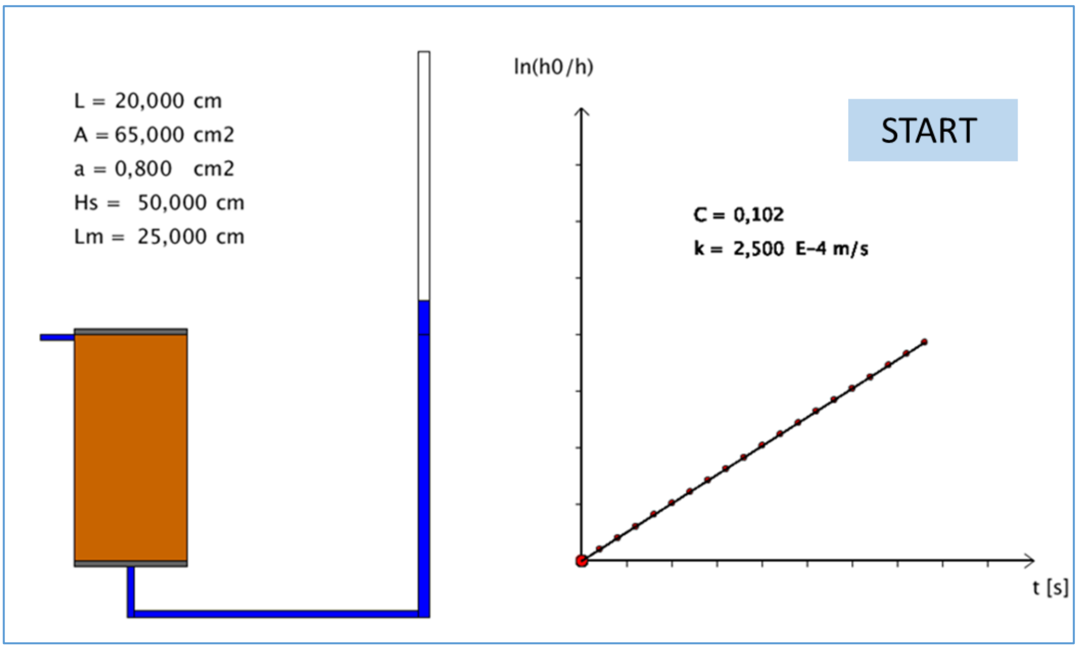


Figure 2. Digital twin model of the falling head permeameter as shown in the monitor. Left: sketch of the experiment. Right: measured heights and times, interpreted according to equation (1). (A = $\pi D^2/4$ = 65 cm^2, a = burette cross section = 0.8 cm^2, h0 = initial height of water level in the burette from top of the sample, k = soil permeability, C = gradient of the straight line, t = time, refer to Figure 1 for other symbols)

The estimation of soil permeability can be carried out from expression (1) linking water height in the burette and time (Terzaghi et al., 1996):

$$\ln\left(\frac{h_o}{h}\right) = \frac{k\,A}{a\,L}\ t \tag{1}$$

where h_o is the initial height of water level in the burette from the water outlet height (which is the top of the sample), h is that current height of water at time t, k is soil permeability, L is the sample height, A is the sample cross section area and a is the burette cross section area. The plot "natural logarithm of height ratio" versus "time" should be a straight line with gradient C,

$$\mathrm{C} = \frac{k\,A}{a\,L} \tag{2}$$

and from that gradient it becomes straightforward to estimate soil permeability, *k*. This estimation is carried out in real time, while the experiment is being performed, thanks to the duality physical model – digital model.

Regarding the electronic devices involved, only an ultrasonic sensor and an Arduino microcontroller are required. Figure 3a shows the ultrasonic 40kHz sensor: a sound is emitted and the reflection on a plate produces an echo that is received. Measuring time allows determining the distance from the sensor to the reflecting plate, l, and that value is used to compute the height of water, h:

$$h = Hs - Lm - l \tag{3}$$

where Hs is the distance from the sensor to the top of the sample and Lm is the length of bar connecting the reflection plate and the floating device in the burette.

Figure 3b shows the Arduino microcontroller and the cables connecting the sensor. Programming the Arduino is quite simple and civil engineering students have the opportunity to learn some basic concepts on instrumentation and microcontrollers. What requires more skills is the development of the digital twin. In this case, the picture and the graph shown in real time in Figure 2 were produced using Java programming language by means of a user-friendly software "Processing" (version 3.3.6).

Typically, sandy soils are used for the experiments, because clayey soils have low permeabilities and the flow becomes too slow for teaching purposes. Section 5 describes the experience of implementing this type of activities in the Civil Engineering curriculum at UPC-BarcelonaTech.

The cost of the materials used in the construction of this falling head permeameter is about 100 euros, associated to the cost of the ultrasonic sensor, the solenoid valve and the Arduino microcontroller (excluding the solid plastic parts).

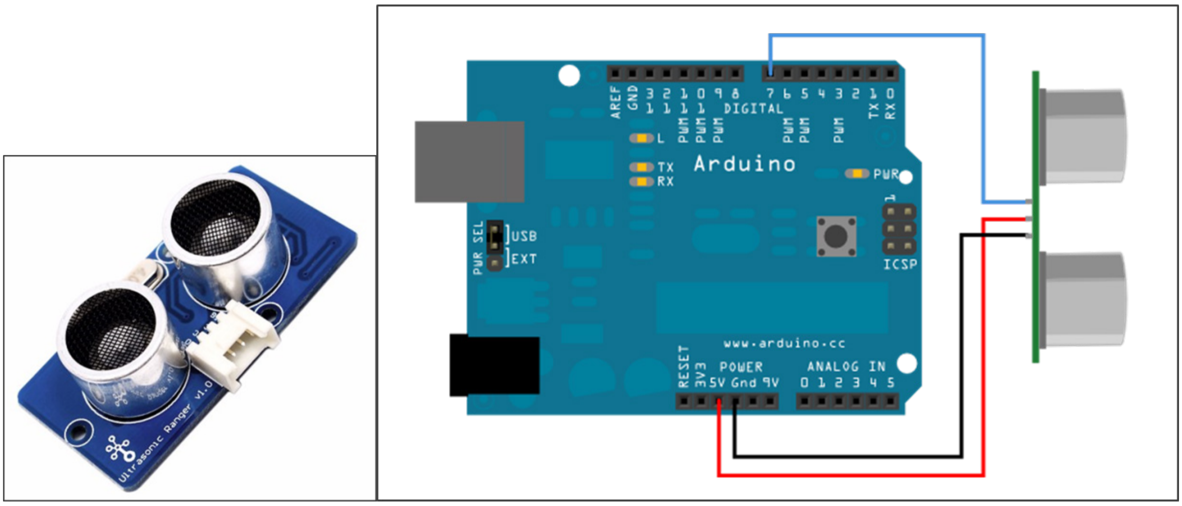


Figure 3. Left: a) ultrasonic sensor. Right: b) Arduino microcontroller and sensor connected

4 A direct shear test apparatus

Another example of the methodology presented above involving low-cost devices in the laboratory is the development of a direct shear test apparatus. This classical test illustrates the important concept of dilatancy in soils, that is, the generation of volume change when a shear stress/strain is applied. Soft soils tend to decrease volume when shearing (negative dilatancy), whereas dense soils tend to increase volume when sheared (positive dilatancy). The coupling between volume and shear distinguishes the behaviour of soils from elasticity and this constitutes a new concept for civil engineering students.

Figure 4 shows the apparatus designed and built by means of a 3D printer. Apart from the solid parts, the other components of the device are:

- An Arduino MEGA microcontroller (with more capabilities than a UNO board, Figure 5)
- Linear guide actuator and stepper motor, to apply an increasing horizontal displacement step by step (Figure 6). Vertical force is constant and applied by means of weights.
- Load cell to measure the horizontal force applied (Figure 7).
- Sensor for vertical displacements based on the Hall effect, that is, the variation of a magnetic field depending on the distance between two magnets (Figure 8).

The device is designed for teaching purposes in a classroom and for the sake of simplicity no water is used. Typically, a dry sandy sample of dimensions 5 cm x 5 cm x 2 cm inside the red box (Figure 4) can be tested. Constant vertical load should be less than 10 Kg to handle the setup (corresponding to a maximum normal stress of about 40 kPa). Horizontal relative displacement is obtained from the stepper motor controlled by the Arduino device. Shear force is obtained from the load cell (Figure 7). Measuring vertical displacement with accuracy constitutes a challenge and the Hall effect transducers have been found to be accurate (Clayton et al., 1989).

This simple configuration is adequate to show the students the concept of dilatancy. If dry sand particles are poured into the box and a low dense sample is "created", a settlement is expected when shearing the soil. However, when dry sand particles are poured carefully and manually compacted with a simple rod to obtain a dense sample, an uplift of the upper part is observed when shearing the soil.

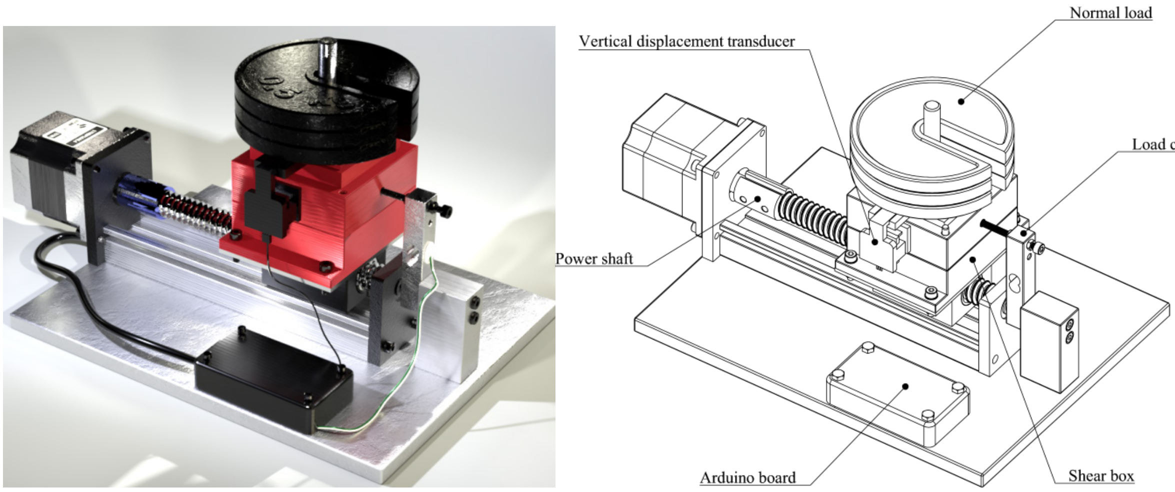


Figure 4. Direct shear test apparatus

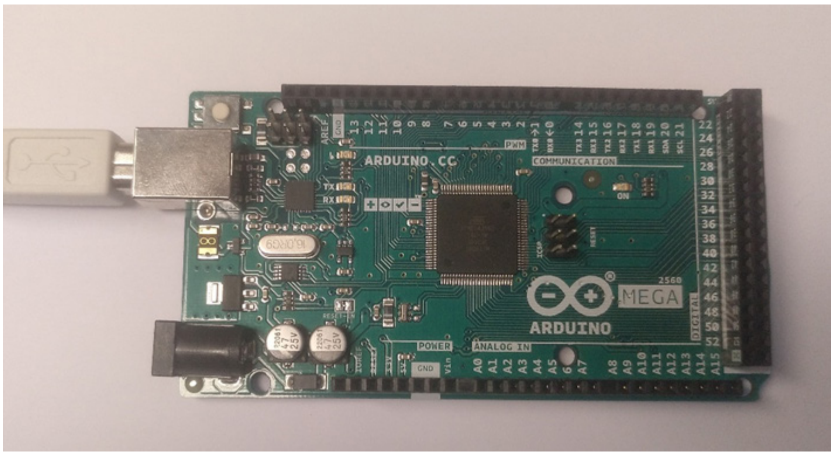


Figure 5. View of the Arduino MEGA board

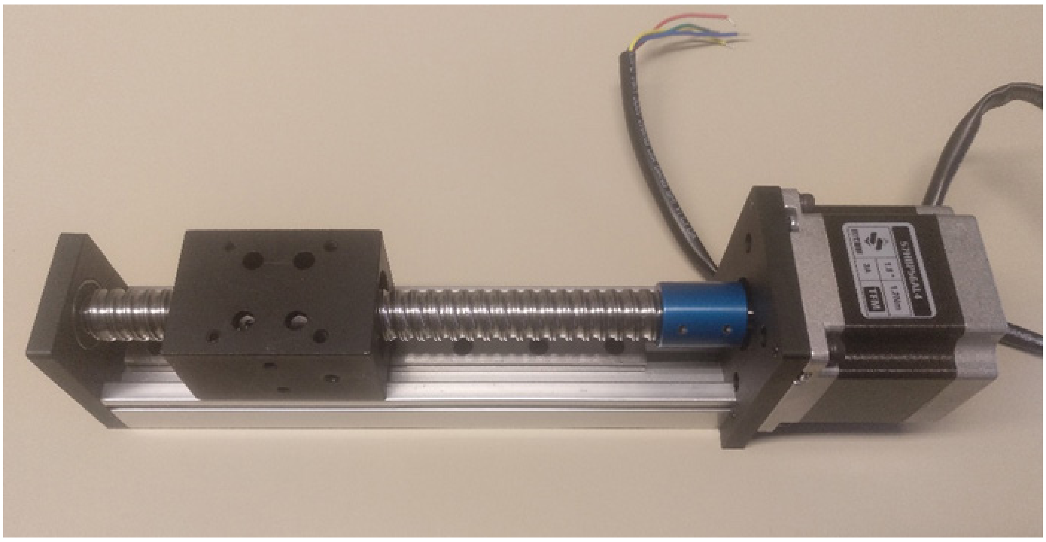


Figure 6. Linear guide actuator and stepper motor

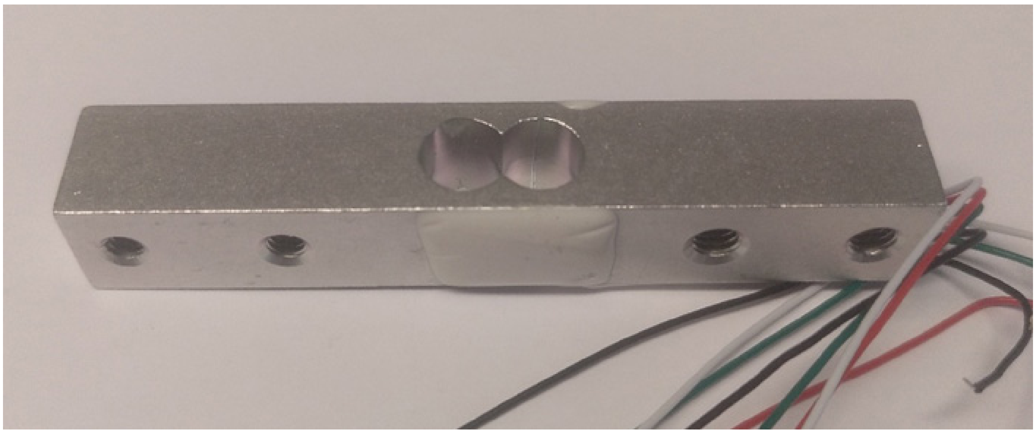


Figure 7. Load cell

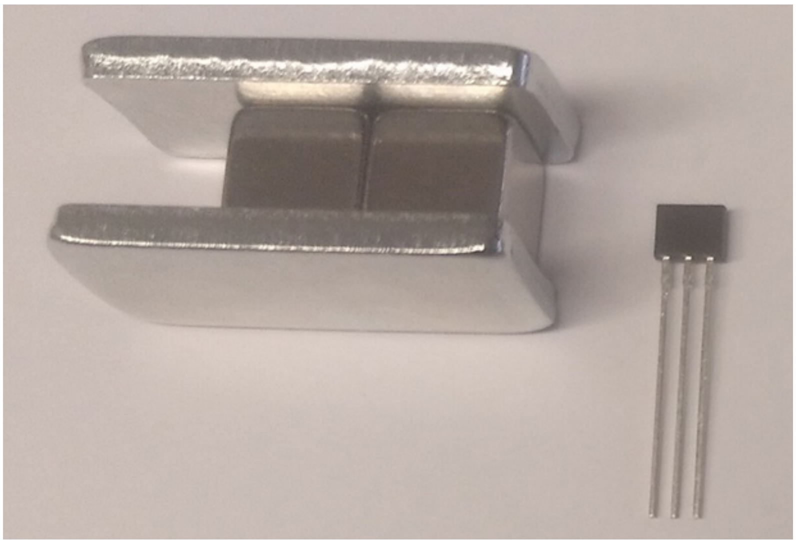


Figure 8. Magnets and Hall effect sensor

Table 1. Cost of the devices used in the direct shear apparatus (euros), excluding the 3D printed items

Device	Model	Function	Cost (€)
Microcontroller	Arduino Mega	Data acquisition and automation	35
Linear guide actuator+ stepper motor	CBX1605-300A +57HBP56AL4	Apply and control linear displacement	114
Load cell + signal conditioner	20 kg load cell +Bluelover Hx711	Measurement of shear force	12
Vertical displacement sensor	Hall sensor 49 E + magnet	Measurement of vertical displacement	3

This direct shear equipment has been developed as a physical model. In this case, a digital twin model has not been developed yet, although it is straightforward from the measurements provided by the sensors and the stepper motor. Normal force is constant and the normal stress is computed dividing the normal force by the contact failure area which is reduced during the experiment. Shear stress is obtained from the load cell measuring horizontal force and computing the value horizontal force over contact area. Horizontal displacement is obtained from the linear guide actuator so the curve shear stress – relative horizontal displacement can be plotted. The vertical displacement sensor (hall sensor) is required to show the coupling between shear deformation and volume change, that is, dilatancy (an effect that cannot be reproduced by the theory of elasticity). Vertical displacements are expected to be small (about tenths of millimetre, depending on the soil density).

The apparatus described cannot be used in general for research or professional purposes. The main drawback is the lack of water (only dry samples are considered) and the low level of stresses applied due to the plastic components used and the “portable” nature of the setup. This is to simplify the design and keep the cost under low values. Table 1 presents that cost and it can be seen that all components cost below 165 euros, excluding the solid parts made with a 3D printer. This is well below the typical cost of a conventional direct shear test apparatus.

Another factor that constitutes a drawback when designing a laboratory low-cost equipment is accuracy, i.e. when measuring displacements of about 0.1 mm. However, in this case, the use of a hall sensor has shown to be convenient for this purpose. In the context of Geotechnical Engineering Education, accuracy when performing experiments is generally not a key issue, as the main objective is to show fundamental concepts. Despite those apparent drawbacks, an improved version of the equipment for standard tests in the laboratory could be built, still at a reasonable low cost if compared with typical prices from industry.

5 Implementation in the Civil Engineering Curriculum

The classical Civil Engineering curriculum has traditionally included some laboratory experiments in several subjects. As a matter of fact, Soil Mechanics BEng students at UPC estimate the permeability of a sandy soil using a classical falling head permeameter, measuring heights with a ruler and time with a chronometer. This is one of the compulsory laboratory works carried out by groups of 3 to 4 students. They spend 3 hours including the preparation of the sample and the setup, performing the experiment and finally observing liquefaction when the hydraulic gradient is too high. They are supervised by a technician and an academic.

The direct shear test is taught to students but they do not perform a test at BEng level. They do that experiment at Master Level (only Geotechnical Engineering students) in teams of 3-4 students, using a fully instrumented device as in professional laboratories. They spend about 3 hours preparing the sample and performing the test, supervised by a technician and an academic. Despite the logic of this approach, there is still room for improvement. By using the open source hardware and software and low-cost equipment, it is possible to facilitate the implementation of laboratory works at undergraduate level and, simultaneously, to show the students several concepts related to the Internet of Things.

With this objective, during the last two academic years, the School of Civil Engineering at UPC-BarcelonaTech has promoted the development of an academic project on Engineering Education aimed at studying the potential of low-cost physical models and digital twins as a pedagogical vehicle for Civil Engineering classrooms. The School has provided some grants ("learning enhancement scholarships") with which students from the 4th year of the BEng degree develop weekly tasks (about 5 hours per week during 3 months), intended to improve teaching within School supervised by academic staff (Chacón et al., 2018). The applications involve several fields, as Steel Structural Engineering, Environmental Engineering, Coastal Engineering and Geotechnical Engineering as well. Some of the developments have been implemented already in normal classrooms.

The initiative of this academic project came from the previous experience of an optional subject on Structural Dynamics at Master Level, which included the development of digital twins as collaborative coursework. Despite the apparent complexity of these devices, the materialisation of these digital artifacts in their simplest form implies the use of a technology, available at low cost under open source conditions: sensors, data acquisition systems and graphical user interfaces. Senior Civil Engineering students can cope with that if they are guided properly.

The School is developing a new Civil Engineering curriculum starting in academic year 2020-21 and, thanks to this experience, a new optional subject on "Digital twins and augmented reality" offered to 4th year BEng students has been proposed. That will require an effort from Civil Engineering students, who are often acquainted with fabrication and programming but not necessarily with electronics. One of the greatest challenges of this type of projects is to assess and, if necessary, remedy the students' lack of background in electronics.

As a consequence of all these initiatives, the popularisation of these techniques among Civil Engineering students is expected to increase, even at Bachelor level. On the one hand, some of the devices developed will be used in normal or laboratory classrooms (i.e. Soil Mechanics). On the other hand, the optional subject on "Digital twins and augmented reality" will provide students with the basic knowledge to develop new devices in the future.

The new falling head permeameter will substitute the conventional device used so far. Three additional devices must be made, as 4 teams work simultaneously in the laboratory. The direct shear test apparatus will be shown in classrooms at BEng level next academic year. Depending on the experience, another compulsory practical work based on this device could be defined in the future.

6 Conclusions

The cases presented, falling head permeameter and direct shear test apparatus, constitute two examples of application of "open-source hardware" as described previously, an extension of the well-known concept of “open-source software”. Apart from that, the concept of “digital twin” adds an extra value to the experiment, as the interpretation of the test is carried out in real time by the user. These tools define a new paradigm in the teaching of practical subjects. They are simple and not expensive so that it is possible to include them in a classroom or in any laboratory environment. Even if the local tradition of the Faculty is more academic and rationalist, or if the budget available is limited, the simplicity of these setups allows to incorporate them in a natural manner when teaching Soil Mechanics. Involving the students in the development of these artefacts is also a useful aspect, as Civil Engineering students are not familiar with these techniques. The future of the Internet of Things relies partly on reducing the gap between monitoring, automation, digitalisation and real applications, and this type of teaching activities contribute to that direction.

Acknowledgements

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Authors’ bios

Alberto Ledesma, Technical University of Catalonia, Spain

Alberto Ledesma is a Professor on Soil Mechanics and Geotechnical Engineering at the Technical University of Catalonia (UPC-BarcelonaTech) in Barcelona, Spain. He obtained his PhD at UPC in 1987, with an extraordinary award for Civil Engineering theses. He was visiting Scholar at Swansea University (UK), during 1988-89, working on finite elements applied to coupled soil dynamic problems. He became a full professor in 2002 and has been involved in research projects including backanalysis, landslides, unsaturated soils, desiccating cracking and numerical methods in geotechnical problems as tunneling in urban areas. He has participated also as Geotechnical advisor in this type of large construction problems. His teaching interests include Soil Mechanics, Numerical Methods and Geotechnical Construction. In recent years, he has participated in local teaching improvement projects in order to change the classical methodologies traditionally used in Soil Mechanics Lectures. He is member of the TC306 Committee on Geotechnical Engineering Education.

Pere Prat, Technical University of Catalonia, Spain

Dr. Pere Prat is an Associate Professor at the Technical University of Catalonia (UPC), Barcelona, Spain, who specializes in Soil Mechanics. He holds his Civil Engineering degrees from UPC-Barcelona and Northwestern University, USA. His main research interests are in the field of geotechnical engineering, localization and cracking, cracking in drying soils, constitutive models for geomaterials, numerical methods applied to geotechnical engineering and coupled problems. In recent years, Dr. Prat has been involved in the development of new methodologies for teaching Soil Mechanics to undergraduate students, proposing mechanisms and activities that have encouraged students’ interest in learning the subject through their active participation in the academic activities. His current teaching research involves the creation of small prototypes for conducting experiments in class illustrating some key concepts of Soil Mechanics that act as catalysts and fixers of the subject-specific competencies as well as developing digital twins of the physical experiments.

Antonio Lloret, Technical University of Catalonia, Spain

Antonio Lloret obtained a PhD degree on Unsaturated Soil Mechanics, graduating in 1982 in the UPC. He is Professor at that University since 2002. He has taught different subjects including Soil Mechanics, Soil Mechanics Laboratory, Unsaturated Soil Mechanics, Instrumentation in Civil Engineering and Geotechnical design. He was selected Assistant Dean of this academic center since 1988 to 1991 and since 1993 to 1994 for Teaching and Learning in Civil Engineering. Since 1983 and for 16 years he was Head of Laboratory of Geotechnical Engineering. During this period, a large number of innovative techniques and test equipment were developed. His main research interests continue to be in unsaturated soil mechanics and laboratory testing and their application to Civil and Geoenvironmental Engineering. A co-author, he has received the 1994 Telford Medal and 2010 Geotechnical Research Medal, both from the Institution of Civil Engineers of London.

Rolando Chacón Flores, Technical University of Catalonia, Spain

Rolando Chacón Flores is a Civil Engineer with a PhD from the Universitat Politécnica de Catalunya (UPC). He is associate professor at the UPC since 2014. His research focuses on the non-linear analysis of steel structures. In particular, structural problems associated with plate buckling, ductility and dynamics. His research involves the usage of numerical modelling and experimental mechanics of steel structures for applied civil engineering design. Furthermore, he focuses on experimental as well as SHM techniques aimed at understanding the in situ behavior of steel and composite structures. In addition, as part of his teaching duties, he has developed innovative educational techniques for civil engineering students. All his work is reflected in numerous articles in international indexed journals. Concerning Plate-Buckling and instability, he has actively contributed to ECCS TC8 and TWG 8.3 in the ongoing development of EN1993.

Mercedes Sondon, Technical University of Catalonia, Spain

Mercedes Sondon graduated as a Civil Engineer in 2011 from the Universitat Politécnica de Catalunya (UPC). In 2016 she obtained a MSc degree in Geotechnical Engineering from UPC. She is currently the head of the Design Area of specialized testing equipment of the Geotechnical Laboratory of the Civil Engineering School of Barcelona. In this position, she designs and coordinates the construction of prototypes for testing soil and rock specimens under thermal, hydraulic and stress changes. She has extended her expertise to the design of complex medium-size testing devices, which are a mock-up of prototype installations. Outside academia, she worked in the period 2009-2013 in the Department of Hydraulic Engineering of ENDESA. She was involved in the design and calculation of several hydro-electric developments in Spain and Portugal. More recently (2013-present) she was involved in Geotechnical consultant work in a variety of aspects: landslides, dams, foundations and harbours.

Supervised Professional Practices: Research as Option to Strengthening Knowledge in Geotechnical Practice

S. Orlandi[1], D. Manzanal[1, 2]

[1]*Universidad Nacional de la Patagonia (UNPSJB), Chubut, Argentina*
sandra.orlandi@gmail.com

[2]*Universidad Politécnica de Madrid, Madrid, Spain*
diego.manzanal@gmail.com

ABSTRACT: Supervised Professional Practices (PPS) constitute one of the requisites to obtain the engineering degree at the National University of Patagonia (UNPSJB). Students need to develop two hundred hours working under the supervision of two tutors. Both are involved in the activity, only one is directly related with the student. Students can develop their PPS in one of the following ways: externally in a company, internally in a university laboratory, or participating in a research project. The number of students who participate as assistants in a geotechnical research project has increased over time. In addition to that, students participate in the development of papers and present in local and regional congresses. There is a possibility that by working side by side with a researcher, students discover their vocation as researchers. In this way students can develop sensibility in the analysis of geomechanical results and acquire knowledge of local soils, while achieving the requirements for PPS. Engineering instructors and researchers that are involved in this kind of practices select volunteer students for their research projects that allow them to identify problems in the new generations of students, who will become future professionals, researchers or engineering instructors. The research option of PPS thus constitutes a two-way road for researchers and students: the former are improving their teaching skills while the latter are being trained in how to investigate.

Keywords: Research, Assistant researcher, Engineering instructors, Supervised professional practices

1 Introduction

Supervised Professional Practice (PPS) constitutes one of the necessary requisites to obtain the engineering degree in Argentinian universities (Ministry of Education resolution 1232/1, 2001). These practices should have a social outreach (Gallegos et al., 2017) and contribute to the student´s training as a future professional (Ferrari et al., 2013). This requisite was included in the Civil Engineering study programme of the National University of Patagonia (UNPSJB) in 2005. The development of competences in the graduate was being pursued, since they were necessary to be competitive in the continuously changing labour market.

In the current context, the PPS can be fulfilled (in the study course, faculty and university seat of the study case) by choosing among three possible options.
1. External Practice, which can be carried out at a private firm or in a governmental entity.
2. Internal Practice, which can be done by working part-time in the university laboratory (LISHA, Laboratory of Investigation of soil, concrete and asphalt), where studies are performed for external companies.
3. Participating in a research project, performed at the LISHA premises, under the supervision of a project director and co-director. The participation can be complete or partial, depending on the student´s interest and availability. Most of the research projects carried out at LISHA belong to the Geomechanics Field. They are subsidised projects (funded by the Research Department of the UNPSJB or by means

of competitive calls by the National Ministry of Education). The projects are directed and co-directed by researchers who have an engineering post-graduate degree training, particularly specialised in Geotechnics or Soil Mechanics.
The aim of the current article is to highlight the growing interest for participating in research oriented PPS at LISHA shown by the students in the last years of the Civil Engineering degree at the UNPSJB, located in Comodoro Rivadavia.

2 Supervised Professional Practices in Argentinian Engineering undergraduate curricula

Supervised Professional Practices (PPS) constitutes one of the requisites for the Civil Engineering students to finish their undergraduate degree. The requisites are distributed along five years. Within this time, students have to pass 42 (forty-two) subjects, 37 of which are annual or four-month courses subjects, one of them being Geotechnics (annual). The remaining five requisites are: three courses, “Human Resources”, “Communication Strategies” and “Language Accreditation” and two extra requisites: PPS and Final Project.

The minimum time required for the fulfilment of the PPS, according to the Academic Regulations, is 200 hours and the tasks included should involve a relation or connection with the social environment. Accordingly, only research projects that have social aim can incorporate students who need to fulfil their PPS.

An important fact is that only those students who decide on their own initiative to take part in research projects have the opportunity to do so during their study course. This is due to the fact that no subject includes this kind of practices in its syllabus, although many subjects do include laboratory practices in which tests are performed, not for training but for information purposes.

In the study case, the group of researchers who are performing investigation activities are focused on the Geomechanics field: Soil Mechanics and Geotechnics. Other fields, such as Concrete Technology and Sanitary Engineering, carry out research projects in a more reduced way. Not all the subjects in the study course have research lecturers, thus limiting the opportunities for the students.

As already mentioned, the PPS can be fulfilled in three ways.

1. External practices, which can be carried out in a private firm or in a governmental entity. For this kind of practices, the students perform a part-time remunerated job. There is an external tutor who supervises the student´s work and an academic tutor who guarantees that the practices performed correspond to tasks related to the study course. The students sign employment contracts for six months to one year, which are extended in most of the cases. This happens when the interns’ development fulfils the contracting party´s expectations (Garibay, 2002).
2. Internal practices developed at the Soil, Concrete and Asphalt Laboratory (LISHA), where projects for third parties are performed. In this kind of PPS, the students are paid for their job. The practices last at least four months and, in some occasions, students can continue after finishing them.
3. Participating in a research project, as an assistant, under the supervision of two research lecturers. One of the lecturers acts as project director, while the other one is co-directing it. In some cases, the students can be paid with subsidised projects funds. In other cases, they can apply for a scholarship granted by the National Intercollege Board (NIB) in the framework of “The Plan of Strengthening of the Scientific Research, Technological Development and Innovation of National Universities” (Ac. Pl. Nº 676/08 y 687/0) for undergraduate degree students from public universities.

The work involved while participating in any of the options is clearly very different with regards to the premises where it is developed, the tasks that are carried out, the remuneration paid and the certification acquired (Orlandi et al., 2016).

2.1 A tool to reduce the students’ graduation time

A recurring problem in the Civil Engineering degree in national universities, is the excessive time taken by the students to get the undergraduate degree. According to statistics presented in local and regional education congresses, the average time is twelve and a half years. Some authors have tried to identify the reasons through detailed studies and statistics analysis (Das Neves, 2015).

In the study programme, which came into effect in 2005, the PPS became a requisite to obtain the undergraduate degree. The research projects, performed at the LISHA premises, from the Civil Engineering degree located in Comodoro Rivadavia began in 1991, while the first research projects in the Geomechanics field date from 2008. During that year, the first students were incorporated as research assistants, without combining investigation with PPS. The new study programme has the curricular distribution shown in Table 1.

Table 1. Number of hours in Civil Engineering at UNPSJB according to the area of the knowledge (Das Neves, 2015)

General subject	Hourly rate [hours]	Percentage [%]	Minimum hours according to regulations [Res. 1232]
Basic Sciences	1260	30.65	750
Basic Technological Sciences	1065	25.92	575
Applied Technological Sciences	1155	28.1	575
Complementary Sciences	300	7.32	175
Elective Sciences	90	2.18	-
Other exit requirements	240	5.83	-
PPS and Courses*	220		

Note: * “Human resources” and “Communication strategies”

PPS can be initiated by students with the 75% of the study course passed, which only occurs after finishing the fourth year. This is the reason why the incorporation of students who have decided to perform their practices in a private company takes place when they are still studying or taking the exams of final subjects. This implies that when receiving a remuneration, students acquire a certain economic independence. It is very clear to detect that this fact might be one obstacle to finish the undergraduate degree (Das Neves, 2015; Orlandi et al., 2016). Especially in a country where the demand for engineers from all the branches of Science is growing constantly (INFOBAE, 2018).

On the other hand, those students who participate in research projects as part of their PPS or in projects for third parties or at the LISHA premises have a brief and flexible work period regarding time. They can adapt themselves to the intensity of the practices developed and the demand during exam periods (Abate & Orellano, 2015).

2.2 Why does PPS, as complement to research, turn out to be attractive to students?

All the students who have participated in research projects were surveyed before and after their participation in the PPS. The answers before beginning included fear to participate in activities for which they were not prepared. However, by the end of the practices, the confidence acquired to analyse results and detect test errors could be seen.

Some companies, where eventually the already graduated professionals were hired, valued the experience in research. The critical spirit, if it is not innate, requires training through practices similar to the ones carried out in a research project (Abate & Orellano, 2015).

In some occasions, this kind of practices awakened the scientific vocation in the students involved. The possibility of pursuing after graduation a Ph.D., a master´s degree or a specialisation came up almost naturally in some of the student-assistant researchers who had participated in the projects.

The participation in the laboratory practices performed in the frame of research investigation is something to highlight, since the students have co-authored the publication of articles in national and international congresses and magazines, such as:

- S. Orlandi, D. Manzanal, E. Miranda & M. Robinson. "Use of Lignin as Stabilizer in Expansive Soils", in Proceedings of the 16th PCSMGE, 21-23 October. Cancún, México, 2019. [Miranda and Robinson are the undergraduate students performing their PPS]
- S. Orlandi, D. Manzanal, A. Ruiz, M. Avila & M. Graf, "A case study on expansive clays in Comodoro Rivadavia city" in Proceedings of the 15th PCSMGE. 15-17 November, 2016. Buenos Aires, Argentina, 2015. [Ruiz, Avila and Graf are the undergraduate students performing their PPS]
- S. Orlandi, D. Manzanal, A. Espelet & A. Ruiz, "About the use of soils as backfilling under roofs and flats: two study pathology cases", Magazine of Geology Applied to Engineering and Environment, vol. 35, pp. 103-114, 2016. [Ruiz is the undergraduate student performing his PPS]

In some occasions, students have participated as lecturers in local Civil Engineering Conferences, encouraging the development, or in some cases the strengthening of presentation skills; for most of them, giving presentations turned out to be a very challenging activity.

2.3 What indirect benefits does the participation in research groups entail for undergraduate students?

Future candidates for graduate courses should appear among undergraduate students. Some of them have clear goals, defined from a very early age. Although a small percentage of students does not have a defined scientific vocation, being part of a research group under the guidance of a committed researcher encourages them to find a new passion for this kind of challenges (Quaranta et al., 2014).

To accomplish this, researchers and institutions are needed to detect these vocations and foster the scientific training (Wesley, 2015), guiding these incipient researching nucleui that are not so easy to maintain over time. The institution where the study case is being developed possesses the required features.

Some of the direct additional benefits for the students which have been detected and fostered over time, are:

- Solving social problems or problems with social impact or generating solutions to problems that have direct impact on society (Álvarez, 2008; Ferrari et al., 2017; Orlandi et al., 2015).
- Developing non-academic skills, such as: team work, oral communication, writing of technical reports, ability to give oral presentations and support ideas, leadership skills, decision making based on knowledge and constant search for information.
- Strengthening of critical and analytical spirit of future professionals.
- Consciousness development about the error analysis from the practical point of view, highlighting the fact that it is also possible to learn from mistakes (Garibay, 2002; Garibay et al., 2008).

Due to the fact that in the laboratories of Argentinian national universities the research projects developed are often at the front end of the national industry, students are trained to become critical future professionals when it comes to interpret the results obtained (Roman et al., 2017). In the case study, the geomechanics laboratory has acquired essential relevance within the study course and the society, becoming a model in the area, not only for its equipment but also for the research lecturers involved.

Due to the limited number of participants in these work groups, the benefits introduced are easy to deploy. The students who choose this kind of PPS strengthen the required aptitude to become responsible, pro-active and analytical professionals, working in a familiar environment, where they have developed their academic training and can find their scientific vocation.

2.4 Candidate profiles

As mentioned previously, the future research assistants in the Geomechanics field are selected among the enrolled candidates during the yearly call issued the last months of the school year. The enrolled candidates are interviewed and considered according to their expectations, skills and personalities. They must have time availability of at least 9 to 12 hours weekly for a period of one year. During partial and final exams, the students are allowed to miss the practices.

Balanced work groups from the beginning promote suitable dynamics for team work. Common interests favour the exchange of ideas and respect towards other´s opinions. Indeed, strongly different characters may create a hostile work environment in which tests must be done repeatedly and the results obtained must be questioned permanently.

Unpaid research work groups, according to the authors’ experience, require a delicate balance between the members of the team. Paid research groups show the same weakness, since the remuneration is typically low in these projects.

Historically speaking, from the beginning of this kind of practices, two students have abandoned the project in which they were working. In both cases, it was due to financial issues. There is no record of cases of abandonment due to problems in the group. With regards to group formation, at times it was necessary to rearrange it in order to ensure the success of the practice.

The number of students of each call depends on different factors: number of research projects, researchers involved and students who have applied.

2.6 Competences: one of the professors' motivations to develop these activities

The process that a student undergoes during a PPS as a research assistant takes around two months of work, shared between the director and the co-director, for any student who is finishing the PPS.

The learning sequence includes the management of standards (IRAM, ASTM, VN) associated to each test, the design and management of a spreadsheet and the preparation and sampling for the test tube shaping. To fully understand the work, students are given some articles to read and present to the rest of the assistants (Santamarina, 2015). The first phase of the PPS requires a lot of dedication from the research lecturers, training and working together with the incoming students. After this period, less presence but more control over the result is required (Montano & Yasbitzky, 2017), together with training and assessment.

The researchers pursue the following objectives through this kind of practices (Atkinson, 2012; Kindelan et al., 2008; Roegiers, 2007)

- Ability to perform geotechnical tests.
- Autonomy to solve everyday situations at a geomechanics laboratory.
- Ability to present their projects during dissemination events (Kindelán & Martín, 2008).
- Acquisition of knowledge and consciousness of soil problems in the area, which originates most of the pathologies found in civil engineering works.
- Strengthening the technical writing by means of reports including the data used to write scientific dissemination articles.
- Team work developing leadership.
- Ability to be proactive.

One of the main challenges the professors come across when teaching to new generations of students is the lack of interest. Keeping the youth motivated is possible, according to personal experience, if curiosity and challenges are used as tools. Everyday work creates discouragement; however, error analysis and searching for the cause of errors usually create motivation if it is well stimulated (Sampieri et al., 2014).

This kind of practices requires previous organisation, for which the research lecturers must be trained permanently (Garibay et al., 2008). Each new group will have a different dynamic, which will necessitate customised organisation approaches. This forces the researcher to be alert permanently to the needs of each new generation of students.

3 PPS research projects at UNPSJB

Since the first research project related to Geomechanics in 2008, the number of students who were incorporated as research assistants has grown. From the year 2014, the students started to participate in the projects as part of their undergraduate training completing the PPS. As mentioned previously, this number depends principally on the number of researchers who carry out these projects. Therefore, as long as the number of research lecturers grows, the number of projects and students involved is expected do the same. Presently, the professors are focused on the training of new researchers, who are starting their Ph.D. and trying to find new candidates to enrol in a Ph.D. program in the students' groups with whom they are working.

In Table 2, the students are divided into four groups. Group I includes the students who began their studies before 2005, when the Civil Engineering curriculum changed, and, hence, do not have as a curricular requirement the completion of PPS. The remaining three groups are students who have a curricular requirement to complete the PPS. They are divided between those who choose to do it in the framework of a research project (group II), those who do it as a professional practice in the LISHA Laboratory dependent on the faculty and Engineering (group III) and those who do the Supervised Professional Practice outside the university, either in a public department or in a private company related to civil engineering as external practice (group IV). The options "external practices" and "working part-time at LISHA" have variable demand according to the local economic situation. On the other hand, considering the growing demand for engineers and the low rate of students over the years, these two options compete to attract students before they graduate (INFOBAE, 2018).

Table 2. Statistics of the number of students and selected options to accomplish with the PPS

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	total
(I)	1	5	1	3	5	4	5	2	3	1	0	1	0	0	0	32
(II)	0	0	0	0	0	0	0	0	0	0	2	2	3	4	4	15
(III)	0	0	0	1	0	0	0	0	0	1	4	4	2	13	2	27
(IV)	0	0	0	0	0	2	1	0	0	1	0	4	4	1	1	14

(I): Student without PPS requirement (Student enrolled prior to 2005, when the Civil Engineering curriculum changed and PPS was incorporated).

(II): Research project as PPS.

(III): Working part time at LISHA (Laboratorio de Investigación de Suelos, Hormigones y Asfaltos).

(IV): External Practice Students.

In the study case, the working areas involved are: unsaturated soil mechanics (specifically compact and not compact expansive soils), sand used for fracking and CO_2 injection in rocky formation. These thematics have a high social impact in Argentina. The research projects have produced articles in local congresses (Civil Engineering Congresses 2016 and 2018 and Geology 2019), national congresses (CAMSIG 2016, 2018), national magazines (Argentinian Magazine of Geology applied to Civil Engineering, ASAGAI and Argentinian Magazine of Engineering Deans, CADI), Latin-American Congresses of Soil Mechanics (PANAM XVI and XVII), and the latest international congress of Rock Mechanics (ISRM 2019)

Moreover, the study case developed in the current article has been presented in national and Latin American congresses in scientific-technological degrees (IPECyT 2018) and in the Argentinian Congress of Deans from Engineering Faculties and Engineering training (CADI 2015 and CAEDI 2018).

From the first student incorporated in 2008 up to now, 21 students have participated as assistants, from which 14 performed their PPS, 2 abandoned the practice, 1 is studying for a Ph.D. supervised by a European University, 2 students who are about to obtain their degree are considering options to start a Ph.D., 2 students were granted a scholarship, 4 students received remuneration from funds from subsidised research projects, while 2 research lecturers were in charge of all the student participants. Likewise, directors and co-directors of research projects were the ones who incorporated the PPS and were responsible for the publication and presentation of technical articles on magazines and congresses.

Regarding the groups of testing in which the students have acquired and are continuing to acquire new skills (Atkinson, 2013) the following can be mentioned:

- Soil classification;
- Determination of volumetric and gravimetic properties;

- Test tube shaping;
- Oedometer test;
- Cutting test;
- Determination of swelling pressure through different tests: oedometer test, expansion under controlled swelling pressure, swelling pressure using standard ASTM, Lambe test;
- Retention curve using the filter paper method;
- Unconfined compression test;
- Triaxial tests: UU, CU and CD;
- Linear contraction;
- Permeability of variable charge permeameter;
- Specific Surface using the methylene blue method.

The incorporation of a bigger group of tests has been considered, yet its fulfilment requires more supervision, which explains the delay in its implementation.

4 Conclusion

The PPS needed to obtain the Civil Engineering undergraduate degree located in Comodoro Rivadavia, at the Engineering Faculty of the UNPSJB, performed through the participation in a research project, constitutes practically the only option for undergraduate students to participate in research projects.

The work developed by students in the Geomechanics field during a PPS helps them acquire knowledge that can be applied by them as future engineers, including the ability to perform geotechnical tests and the determination of design parameters, the identification of problematic soils, as well as the development of technologies that can be applied in local industries. The students also strengthen general skills they will need along their professional life, such as technical writing, oral communication, autonomy, decision making, leadership, team work.

The development of PPS takes place inside a work environment, in which they are immersed from the beginning of their study course. This fact allows to reduce the time needed to develop the activity. Hence, students can obtain their undergraduate degree in a time shorter than the average, which is about twelve years for engineering degrees in Argentina.

The researchers who participate in this kind of practices are interested in forming permanent work groups, where students take part in investigations, fulfil their PPS, are trained in the Geomechanics field and are thus able to better choose whether to continue their education by enrolling in a Ph.D. program or to look for a professional employment. The process at UNPSJB began only fifteen years ago and it is not totally established yet. Indeed, a greater amount of researchers completely devoted to attract Ph.D. students is needed, as well as a higher number of research projects in which more students could be participating.

While this is happening, it is the opinion of the authors that the undergraduate students who have already had the opportunity to participate in a PPS end up their study course better prepared to face professional challenges, equipped with not only technical but also attitudinal knowledge that will clearly make a difference among their peers. Likewise, this tool allows the possibility of creating a link with the society they are immersed in, looking for solutions for social needs through their projects.

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Authors' bios

Sandra Orlandi, Universidad Nacional de la Patagonia San Juan Bosco, Argentina

M.Sc. Sandra Orlandi was born in Comodoro Rivadavia, Patagonia, Argentina. She graduated as a Civil Engineer at the Universidad Nacional de la Patagonia San Juan Bosco (UNPSJB) and subsequently did her Maestría en Ingeniería at the UNAM (Universidad Nacional Autónoma de México), where she specialized in Geotechnical Engineering and Geomechanics, working with Prof. Gabriel Auvinet. She is currently doing her Ph.D. at the Universidad Nacional de la Patagonia San Juan Bosco, working with Prof. Diego Manzanal. She is an assistant professor and consultant at the UNPSJB. Her main technical areas of interest are the behavior of highly expansive soils, soils improvement with polymers, forensic geotechnical engineering and foundations. She is working for the last ten years with Dr. Diego Manzanal in several research projects involving undergraduate students. Both share a passion for research-based geotechnical education.

Diego Manzanal, Technical University of Madrid, Spain

Dr. Diego Manzanal is an assistant professor at the Technical University of Madrid (UPM) who specializes in the field of Geomechanics. He holds his Civil Engineering degrees from Universidad Nacional de la Patagonia San Juan Bosco (Argentina) where he is visiting professor. He obtained a Master degree at Geotechnical Laboratory at CEDEX (Spain) and his Ph.D. at UPM. His research interests involve the constitutive behavior of geomaterials (soils, rocks, cement) for different geotechnical and geomechanics applications. His involvement in research education on civil engineering focuses on project-based learning.

A Study Evaluating Students' Long term Understanding of Effective Stress and Suggestions for its Improvement

D.T. Phillips

University of Limerick, Limerick, Ireland
declan.phillips@ul.ie

ABSTRACT: The effective stress principle is the crucible of soil mechanics; it controls all soil behaviours of interest to the geotechnical engineer. Since its formal postulation by Terzaghi in the 1920's, it has become core to every course in soil mechanics. Applying the effective stress principle in ground conditions that differ from the simple profiles presented when the subject is first introduced poses many difficulties for students. The simplicity of the principle means it can be covered in just a few pages of a textbook but this does little to promote understanding of the subtleties entwined in the principle. For example, issues such as the influence of static, flowing or capillary water on effective stress are rarely covered in a single location in textbooks, nor are these influences linked to the role they play in geotechnical design. This paper presents the findings of a study that evaluates the ability of undergraduate students to apply the effective stress principle in various geotechnical designs. Students in the study were taught the principle in an introductory soil mechanics module and their understanding was evaluated at the start of a follow-on soils module that commences after the summer recess. The results indicate that only a hazy recollection of effective stress remains and imply that careful attention to the teaching approaches employed are necessary if students are to retain their knowledge and proficiency in applying the effective stress principle in geotechnical design. Suggestions for enhancing learning in this area are provided.

Keywords: Effective stress, teaching and learning, soil mechanics, threshold concepts

1 Introduction

The effective stress principle is a core concept in soil mechanics that controls all soil behaviours of interest to the geotechnical engineer. It is essential that students clearly understand the principle and can apply it to any ground conditions encountered on site. To succeed in this endeavour it is necessary to specify the tasks we expect the students to be able to undertake after studying effective stress. In most undergraduate programmes the following skills are required:

1. Calculate total stress profile in a multi-strata ground profile including any applied loads from foundations or embankments.
2. Calculate the pore water pressure under hydrostatic conditions.
3. Calculate the effective stress under dry or hydrostatic ground water conditions.
4. Demonstrate by calculation the impact of a rising or falling water table on effective stress and hence explain why flooding has no impact on effective stress.
5. Calculate the effects of capillary water on effective stress and discuss why its beneficial effect is normally ignored in geotechnical design.
6. Calculate the effective stress in a ground profile when an upward or downward hydraulic gradient exists.
7. Determine the factor of safety against heave when excavations take place in fine-grained soil subject to artesian conditions.
8. Sketch the total stress, pore water and effective stress profiles for any of the above scenarios.

9. Discuss the implication of seepage forces on the geotechnical design of shallow foundations and show how the bearing capacity equation is modified to take account of upward seepage.
10. Discuss and illustrate the influence of soil permeability on the short and long-term stability of excavations when an upward hydraulic gradient exists.

The question arises, should all these skills be taught together or should some items be deferred until the relevant application is being covered in class. Time constraints in a semesterised system mean that some items on the list are often omitted or receive only cursory mention when effective stress is being taught. This coupled with ambitious syllabi generally result in what Gardner (1993) calls, 'the greatest enemy of understanding is coverage.' An incomplete understanding is the inevitable outcome when a lecturer attempts to deliver a dense syllabus within a 12 week teaching semester. The general approach taken at the University of Limerick (UL) is to teach through applied problems or triggers that carefully contextualise the learning within a given geotechnical application. A summary of how the geotechnical offerings are structured in UL's four-year undergraduate civil engineering programme is provided in Table 1.

Table 1. Details of fifteen-week undergraduate geotechnical modules at the University of Limerick

Module Code, Title & ECTS Credits	Task type &	Hours/week	Year	Group based design trigger for Learning	Knowledge required to find a solution (Syllabus)
WT4014: Introduction to Geology and Soil Mechanics 6 ECTS Credits†	C*	2	2	Design a flood embankment to protect university buildings from the River Shannon bursting its banks.	1. Effective stress 2. Seepage 3. Compaction 4. Soil description and classification 5. Introductory site investigation – trial pitting
	E*	1			
	PBL*	2			
	IL*	5			
CE4015: Soil Mechanics 6 ECTS Credits†	C*	3	3	Design a suitable shallow foundation system for a multi-storey reinforced concrete building on a specific site (Part of an integrated design project – the structure and site change annually).	1. Shear strength 2. Bearing capacity 3. Elastic stress distribution due to loading 4. Settlement & consolidation 5. Soil structure interaction
	E*	1			
	PBL*	2			
	IL*	4			
CE4048: Geotechnical Engineering Design 6 ECTS Credits†	C*	3	4	Geotechnical design of piles, slopes and retaining structures using site-specific geotechnical reports.	1. Lateral earth pressures 2. Gravity and flexible retaining wall design 3. Slope stability 4. Pile design 5. Traditional and modern site investigation techniques.
	E*	-			
	PBL*	-			
	IL*	7			

*C: Class, E: Experimentation, PBL: Problem based learning tutorial, IL: Independent learning.

† 1 ECTS credit = 25 hours of student work.

The paper presents the findings of a short study that assesses how well undergraduate students understand the principle of effective stress having already studied it in an introductory soil mechanics module (WT4014). Four months after completing WT4014, the students are re-examined on the effective stress principle. In week one of module CE4015, students are informed that a comprehensive understanding of the effective stress principle is necessary for their project and are encouraged to review their prior knowledge on the principle in preparation for an end-of-week quiz. Their project involves the geotechnical design of a shallow foundation system to support a multi-storey building. The design criteria requires the foundations to be stable and that the total and differential settlements are tolerable. The quiz, which carries zero credit, involves ten conceptual and technical questions designed to elicit understanding of the principle and its application in various geotechnical design scenarios. Following this, four one-hour review classes involving the demonstration of effective stress calculations for a number of applications take place. The time allocated to these review classes is equivalent to approximately 10% of CE4015 class time. A second quiz with similar conceptual and technical questions is administered at the end of week three. Finally, after the results and feedback from both quizzes have been received, the students write a short reflection on their performance and understanding of effective stress. The second quiz and the reflective exercise are worth ten percent of the module grade. The review concludes with a tutorial involving a number of physical demonstrations (discussed later) which is designed to target the areas the students found challenging, this is delivered at the start of week 4.

Given its importance, the author believes it is worth investing the necessary time to apply the effective stress principle in various geotechnical applications. The review should take place at the expense of more procedural course content as these can be learned by reading a textbook and undertaking practice problems. For example, techniques for determining t_{50} and t_{90} from oedometer tests, secondary consolidation and settlement predictions in coarse-grained soils were omitted from CE4015 in this study to provide the time to review effective stress. Insights gained from this exercise along with the students' reflections are presented and suggestions for enhancing learning in this area are offered.

2 Challenges in Teaching Effective Stress

The effective stress principle is a threshold concept that students must master if they are to become good geotechnical engineers. Didau (2015, p160) quoting Meyer & Land (2003) defines a threshold concept as one where a learner crosses that liminal or in-between space of 'not knowing' and enters the space of knowing. Once this transition is made, the new material cannot be unlearned and it changes the way the learner sees the subject for the better. The focus of the teacher should therefore be to develop an integrated teaching approach that contextualises and unifies the geotechnical applications that involve determining effective stress.

The effective stress principle is so deceptively simple it tends to be presented in a 'matter-of-fact' way without significant discussion on how it controls the engineering behaviour of soil - at least this author has been guilty of such an approach. A review of a decade of examination results for WT4014 confirms effective stress is an 'arena of struggle' for young engineers. Over this time, results show the students obtaining little more than a passing grade on this essential topic. While a semesterised educational system presents obstacles to developing a deep understanding of the effective stress principle, there is a need to re-examine how the topic can be best taught within such constraints.

The author's experience suggests the students find determining the pore water pressure the more challenging component in the effective stress equation, probably because ground water conditions are highly variable. The following excerpt from Terzaghi's writings alludes to this '… in engineering practice, difficulties with soils are almost exclusively due not to the soils themselves but to the water contained in their voids. On a planet without any water, there would be no need for soil mechanics' (Goodman, 1999). The calculation of pore water pressures is a re-occurring conceptual and technical challenge for students that must be addressed before learning can take place. The following paragraphs outline the issues frequently encountered by the author:

2.1 Conceptual Challenges

- Students struggle to explain the effective stress principle in a way that indicates they have developed a clear understanding of its importance in geotechnical engineering. Table 2 shows a typical student response when asked to explain the principle. The question was initially asked after the summer holidays, some four months after the students were first introduced to the principle (Table 2(a)).

Table 2. Student response when asked to explain the effective stress principle

(a)	Quiz 1	$\boldsymbol{\sigma' = \sigma - u}$ Effective stress = total stress – pore water pressure. The strength of the soil taking the presence of water into account.
(b)	Quiz 2	The stress in the soil due to the friction between soil grains. If water is present in the soil, it has a buoyancy effect which decreases the effective stress.

Two weeks later and following some review classes, the answer to the same question is given in Table 2(b). Table 2(a) shows the memorised effective stress formula but no evidence that the student actually understands what is happening in the ground. There is only an incremental improvement in understanding evident in the second answer. Scrutinising tens of similar answers prompted the need to change how the topic is presented in this iteration of CE4015 and in future iterations of WT4014.

- Providing the conceptual framework that underpins the analytical formulation of the effective stress equation is also important. Some may deem this unwarranted, given σ' is not the actual grain-to-grain contact stress but rather the average stress over the loaded area. Nevertheless, the author has found the following rationalisation of the principle a useful learning aid for students. Considering Figure 1, the external force F applied to a confined saturated soil mass is shared between the inter-particle forces f and the pore water pressure u.

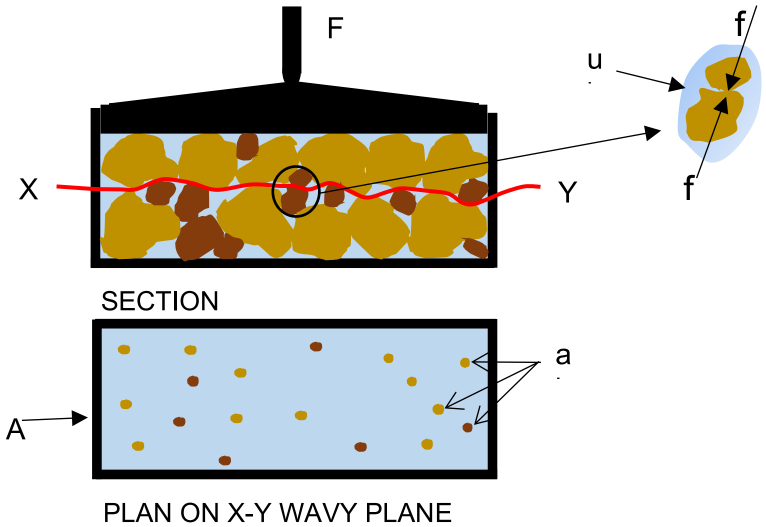


Figure 1. Conceptual derivation of the effective stress equation

In considering the vertical effective stress in the ground, we consider only the vertical components of these forces (f_v). We can write the vertical equilibrium equation representing the balance of forces across the wavy plane x-y, which is tangential to the grain contact points.

$$F = \sum f_v + u(A - \sum a)$$

'A' represents the total plan area of the plane and 'a' represents the average area of an individual grain-to-grain contact along the plane. Dividing both sides by 'A' gives

$$\frac{F}{A} = \frac{\sum f_v}{A} + \frac{u(A - \sum a)}{A}$$

We note F/A represents the total stress (σ) acting on X-Y and $\Sigma f_v/A$ represents the stress in the soil skeleton which is known as the effective stress (σ'). Rewriting the equation, we get

$$\sigma = \sigma' + u(1 - \frac{\sum a}{A})$$

The effective stress clearly depends on the value of $\sum a$ but since the inter-granular contact areas between soil grains are relatively small, $\frac{\sum a}{A}$ is negligible and can be ignored (Budhu, 2009; Knappett & Craig, 2012) and the above equation can thus be simplified to σ = σ' + u. It is helpful to emphasise that σ represents the external actions on the soil element being considered while (σ' + u) represents the internal response of the soil element to the external actions. As water cannot transfer shear stress, the stress induced by any applied loads must ultimately be resisted entirely by the soil skeleton through σ'. It is for this reason that the effective stress equation, in its truncated and approximate form, is normally presented as follows:

$$\sigma' = \sigma - u$$

- The occurrence of water in the ground is a useful starting point when setting the context for evaluating pore water pressures. The water table is defined as the location in the ground where the pore water pressure is zero. Below the water table, pore pressures are positive and thus reduce the effective stress. In fine-grained soils, surface tension effects cause the water to rise above the water table by capillary action. The capillary water causes suction or negative pore water pressure which results in an increase in effective stress. This enhanced effective stress is generally ignored in geotechnical design as an influx of water from rainfall or a rising water table causes the surface tension to breakdown as the pore pressures become positive; this phenomenon is clearly demonstrated in Burland's (2014) sandcastle experiments.
- Clear distinctions between pore water pressure and free water is essential, as this is often a source of confusion for the novice. Understanding that a full hydrostatic pressure can develop within very narrow interconnected void spaces (as is the case in most soils) is essential. This can be demonstrated by placing a transparent straw in a glass of water and noting that the vertical depth of water (h_w) in the straw corresponds to the depth of water in the glass (Figure 2a). If dry sand is then poured into the glass, displaced water will overflow but the depth of water in the straw remains the same (Figure 2b). The pore water pressure u at a given level is directly related to the depth of water according to $\gamma_w h_w$ where γ_w represents the unit weight of water and h_w is the height of water. The orientation (or shape) of the straw has no effect on u. Free water on the other hand is the water sitting in a glass (Figure 2a) or water located above the soil line (Figure 2c). In the case of Figure 2(c), the pore water pressure at the base of the glass remains the same as in (a) and (b) but we see the free water also contributes to the total stress at the base by an amount equal to $\gamma_w z_w$. The additional total stress from the free water is ultimately cancelled out when we calculate the effective stress i.e. $\sigma' = (\gamma_{sat} z_s + \gamma_w z_w) - \gamma_w(z_s + z_w)$ where γ_{sat} is the saturated unit weight of the soil. Thus the effective stress at the base of the glass in this case is equal to the submerged unit weight γ' of the soil multiplied by z_s, the depth of soil. This simple demonstration illustrates that free water above the soil line has no impact on effective stress and explains why the effective stress in soil say 1 m below a shallow river is the same as if the soil is located 1 m below a deep ocean.

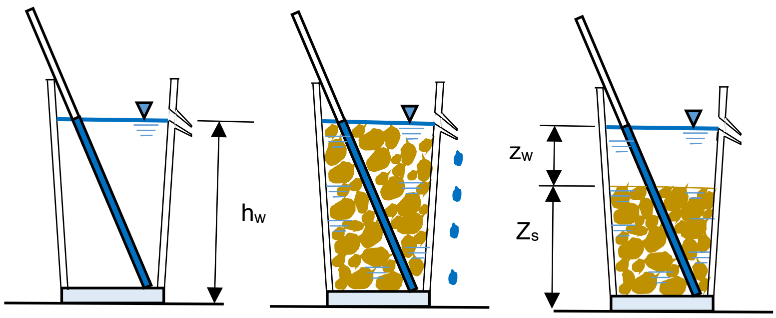


Figure 2. Conceptual representation of effective stress, pore pressures effects

- Ground water is rarely static. When it flows its impact on the magnitude of effective stress is significant. In coarse-grained soil, downward water flow increases effective stress and induces ground settlement but the more onerous condition is when seepage is upwards. Upward flow creates a frictional drag on the soil that opposes the self-weight of the soil grains and adds to the buoyancy effect thus decreasing further the force with which the soil particles press against each other. If the combined upward drag forces and the buoyancy forces exceed the soil's weight, the particles tend to lift off one another and the soil becomes a liquid mass with no strength.
- Conversely, when fine-grained soil is present, for example an alluvial flood plain overlying an aquifer, the pore water pressure may increase within the aquifer due to a rising water table or surface water entering the aquifer at an outcrop. The associated increase in pore water pressure in the aquifer is 'locked in' by the overlying low permeability stratum thus creating artesian

conditions. Construction under artesian conditions can present challenges such as those discussed in Section 2.2.1.

2.2 Technical Challenges

The response to loading in saturated fine and coarse-grained soils give rise to different short-term and long-term soil behaviours. Comprehending the nuanced differences between these conditions is essential when evaluating effective stress in seepage and strength calculations. Wesley (2019) suggests that identifying these differences on given sites proves troublesome for some engineers. These are discussed with the aid of teaching demonstrations in the following sections.

2.2.1 Stability and Pore Water Conditions

Base instability in excavations can be initiated by either a ‘reverse’ bearing capacity failure or a seepage failure. Focusing on failure due to seepage, two situations must be checked 1) a short term or base heave situation created by artesian pressures beneath a fine grained soil and 2) steady state seepage causing ‘boiling’ in excavations. Dealing with these can be challenging for students as textbooks do not often draw attention to these differences and when they do, the distinction is not normally discussed at the same location in the book. If both stability scenarios are not presented, students will be unaware of the checks that need to be undertaken to assess base stability when a hydraulic gradient exists within the ground. Ishibashi and Hazarika (2015 pp. 111-127) cover both situations in their book and Atkinson (2012, pp. 3-7) presents an interesting problem also covering both scenarios. Classroom demonstrations such as those illustrated in Figure 3 are helpful in enhancing understanding of seepage effects and these can also be used to predict the effective stress at failure if the soil properties are provided.

a) Building collapse due to upward seepage

b) Seepage failure in an earthen dam

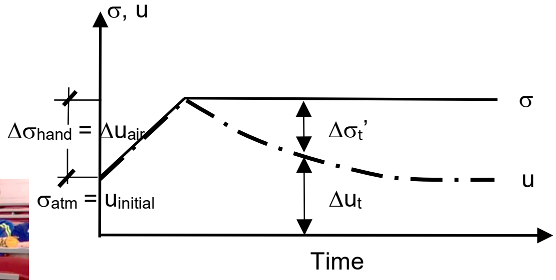
Figure 3. Simple classroom demonstrations to illustrate seepage effects on soil behaviour

2.2.2 Drained vs. Undrained Loading Conditions

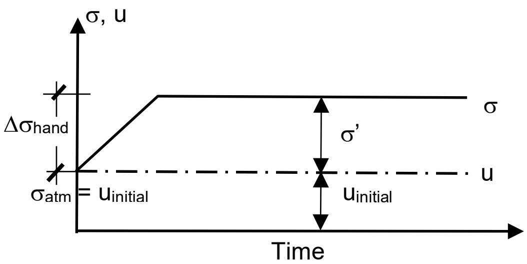
Identifying the drainage conditions in the ground is key to undertaking the correct geotechnical analysis. The conceptual background to assist in making this decision is provided in CE4015 via short online videos which the students are required to view ahead of class (Phillips, 2015 a & b). This approach is known as flipping the classroom and allows class time to focus on the material students find difficult. The magnitude of effective stress is influenced by the drainage conditions within the ground. A qualitative understanding of this can be obtained when each student undertakes the simple in-class experiment shown in Figure 4a. The permeability of coarse and fine-grained soil is simulated by varying the number of apertures created by a needle in bags of potato crisps; a large number of apertures represents the high permeability existing in a coarse-grained soil while a small number of apertures in a second bag represents the low permeability of a fine-grained soil. After the apertures are made, the initial air pressure inside each bag is equal to the atmospheric pressure i.e. $u_{initial} = \sigma_{atm.}$ If a load is then gradually applied by hand to each bag ($\Delta\sigma_{hand}$), the students can sense the rate of change in internal air pressure (Δu_{air}) as $\Delta\sigma_{hand}$ increases for each ‘soil type.’ The change in internal air pressure in each bag i.e. the pore pressure can be qualitatively sketched with respect to time for both scenarios as shown in

Figure 4b. From these plots, the students can extrapolate how the 'effective stress' changes over time as $\Delta\sigma_{hand}$ transfers to Δu_{air} and from this to effective stress through the potato chips (σ'_{chips}). Figure 4b(i) shows there is a delayed response in the transfer of Δu_{air} to σ'_{chips} in the bag having a small number of apertures. Significant time elapses before Δu_{air} dissipates to reach $u_{initial}$ and the audible 'crunch' of the 'crisp skeleton' is heard as it accepts the load through σ'_{chips}; this is analogous to the behaviour of a saturated fine-grained soil. Figure 4b(ii) illustrates the case for the bag with a large number of apertures. In this case, the time to 'crunch' is minimal since the air pressure remains at $u_{initial}$ and the applied load immediately transfers to the crisps as σ'_{chips}; this represents the rapid increase in effective stress experienced when coarse-grained soils are loaded.

(a) Classroom demonstration simulating drained and undrained behaviour using bags of potato crisps.



(i) Fine grained soil response.



(ii) Coarse grained soil response.

(b) Loading responses of fine and coarse grained soils.

Figure 4. Demonstrating influence of drainage conditions on effective stress

3 Change in Teaching Strategy

The effectiveness of students' learning depends on many factors including their interest in the subject, their maturity, their active engagement in class (by doing some task) and their attentive capacity while studying. With the exception of engagement, most of these factors are outside the control of the lecturer. What is within the lecturer's control is how the information is organised and presented.

Regardless of efforts made to meet students' learning preferences, time to assimilate new concepts is required and therefore it is argued that introductory soils modules should be built around the effective stress principle. A comprehensive treatment of this topic with adequate time for students to be assessed and receive feedback is an excellent investment in the development of a geotechnical engineer.

Measurement of learning is traditionally evaluated through heavily weighted end of semester examinations. These tend to focus on student performance rather than student learning. Continued use of this assessment tool encourages cramming information into short-term memory for recall in the examination. This knowledge is quickly forgotten as evidenced by the results discussed in Section 4. Therefore, a new model is required if students are to learn effectively, a model where retained information can be recalled and applied in new contexts. There is overwhelming evidence in the teaching and learning literature of the limited value of a traditional didactic lecture as a learning experience (Deci & Flaste, 1995; Prensky, 2001; Goodhew, 2010; Pink, 2010; Felder, 2012). Karpicke & Grimaldi (2012) and Didau (2015) suggest that a better approach is to teach a concept once followed by multiple assessments to embed and reinforce the concept. This approach along with the extensive use of technology and classroom demonstrations is adopted in this study.

4 Results of Quizzes and Discussion of Student Reflections

The quiz results are shown in Figure 5. The results from quiz 1 (n = 35) compared with the WT4014 results from similar end of semester exam questions revealed that an average class grade reduction of 50% took place over the summer period. The quiz 2 (n =32) results show a marked improvement on student performance. However, their knowledge remains 25% lower than the average pre-summer result in WT4014. It is disappointing that the quiz 2 results are not higher given the first four questions were identical to those in quiz 1. Questions 1 to 4 sought to elicit the students' conceptual understanding of effective stress by seeking explanations of the principle in their own words, the impact of artesian conditions on the stability of excavations and how the calculation of stability would differ if excavations were undertaken in i) coarse grained soil and ii) fine grained soil. The students struggled with such questions and produced regurgitated learned definitions with little evidence of understanding the physical implications of the effective stress equation on soil behaviour. Interestingly, the students exhibited less difficulty in calculating the magnitude of effective stress when the depth of static water varies in the ground including when it is above ground level. This suggests a certain parrot mentality towards the learning of soil mechanics. Questions calling for an awareness of short-term and long-term stability of excavations also posed problems. Students tended to perform stability calculations based on steady state hydraulic gradients despite the ground profile indicating the presence of fine-grained soil overlying an artesian basin – thus the need to check against base heave rather than piping. A marked improvement was noted in the end of semester exam. All students (n=37) attempted the questions involving effective stress. The results show the average class grade improving by over 200% on the quiz 1 result.

The improvement in the final exam is believed to be attributed to 1) a combination of time devoted to discussing and reflecting on how effective stress influences soil response under different rates of loading and ground water conditions and 2) on the 'teach once followed by test frequently' approach adopted in this study.

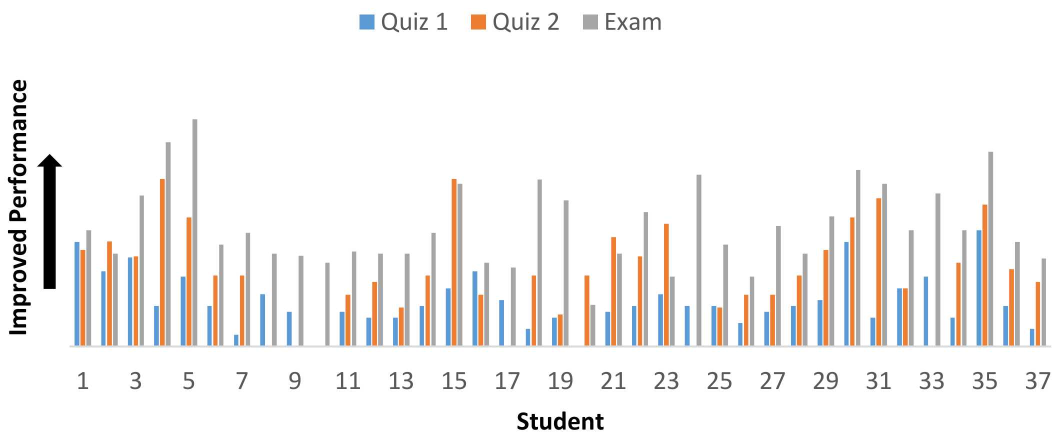


Figure 5. Results from tests on effective stress examinations

The following selection of reflections give a useful insight into the students' thoughts and perceptions. Students clearly realise that success can only be achieved through dedicated study but they also remind us that 'what gets measured is what gets done':

> 'The reason why I did so poorly in the effective stress quizzes is that I was convinced that I remembered enough of the topic from last semester. I feel that my understanding of effective stress has declined over the summer due to lack of practice and having not looked at effective stress in a few months I had forgotten a lot of the trickier bits.'

> 'My performance was poor in the first quiz due to my lack of preparation … I felt it wasn't worth the time, especially when it wasn't counted towards my final grade. My result went down in the second test, mainly because I wasn't prepared enough. I had missed a couple lectures prior to the test which didn't help. In the exam I knew that I should have known how to answer the questions which in turn frustrated me.'

The following comments highlight the importance of revisiting important concepts in class and providing timely feedback to assist learning:

> ' …. I thought these quizzes and the lectures spent reviewing effective stress were very useful as often when we complete an exam for a module the material is soon forgotten unless we are given a reason to think about it again. I also feel that it will be easier to further progress my knowledge of soil mechanics in this module now that I have a better understanding of the basic principles. I have also learned the importance of going over material several times in order to get a deeper understanding of it.'

> 'I feel my understanding of effective stress did not improve after the quizzes but it has after the tutorial class we had today. Going through the quiz questions helped and showed how simply the questions can be answered when you understand what's going on within the question.'

> 'I feel the extra (post quiz) tutorial really improved my knowledge of effective stress. It made it more realistic and easier to understand as it was easy to visualise.'

The following quotations highlight the importance of drawing on prior knowledge to solve new problems. They also highlight the role played by careful and meaningful study to develop competence around effective stress:

> 'The quizzes highlighted to me that just because something was done in a previous module doesn't mean I could forget about it as it won't be needed again in further modules. While revising I realised I was just learning how to produce a certain answer for a certain question without fully understanding the problem. It was clear that I did not understand the question being asked and I was only just reproducing the same method for each question just hoping the numbers would fill in and I would get the correct answer. I found (the post-quiz) soils tutorial very helpful … It enabled me to get right back to the basics of what was being asked and leading to me being able to understand what was actually happening and being examined in the question.'

> 'The main issue is how I study. I need to figure out a better system of actually absorbing information and then testing my own knowledge before I go into an exam. Staring at or simply reading over my lecture notes does not mean the information is going in.'

> 'Quiz 1 made me aware that I did not have an understanding of effective stress… when asked to explain with sketches or in my own words, I did not have a good enough understanding to do so. The post quiz in class illustrations to describe what was occurring greatly developed my understanding of effective stress.'

> 'This has been a beneficial learning process from a personal point of view. The two-quiz method is something that I have rarely completed in the past and having done so I can say it is a very good way to see can you improve as an individual and upon reflection I can clearly see simple mistakes I made in both quizzes but also how my knowledge and understanding has been developing.'

5 Conclusions

This paper has reported on the teaching of the effective stress principle to undergraduate civil engineers. In doing so, it has documented a number of obstacles and challenges to learning observed over the past decade. Demonstrations and teaching approaches that have proven effective in assisting the students understanding of the principle and their ability to apply it in different geotechnical design applications are presented. What becomes evident from the study and is reinforced by the students' reflections is that learning only loosely correlates with what the teacher does but strongly correlates with what the student does. Nevertheless, the following useful insights emerge from the study:

- Undertaking effective stress calculations linked to construction scenarios contextualises the calculations within a design setting and promotes the development of a holistic understanding of the role effective stress plays in geotechnical practice. The process by which the student assimilates this understanding is fraught with challenges and it is certainly not a linear process as might be suggested by our carefully sequenced learning outcomes. It requires time and multiple repetitions before understanding is achieved.

- The 'teach once followed by numerous testing' approach has significantly improved the overall class understanding of effective stress. As a result, the introductory module, WT4014 will incorporate this teaching methodology in the future.
- Reflection in engineering education should be encouraged and should receive the same status as performing computational exercises. Without reflection, gaps in knowledge or poor study practices are not identified and corrected. To establish this status in the students' minds, course credit needs to be awarded for written reflective exercises. A mere suggestion that 'engaging in reflective practice is good for your professional development' is a poor motivator and is unlikely to spur the student into action. Once the habit has been formed and the benefits of reflecting garnered, the need for any incentive becomes obsolete.
- Many repetitions of the core concepts are required if they are to be etched into the brain's long-term memory. We must be prepared to devote the time required to achieve this goal even if this comes at the expense of a reduced syllabus.
- We must be mindful in our teaching to engage as many of the senses possible through use of classroom demonstrations, videos, clickers and in class activities that motivate students to learn.
- A student's decision to learn is entirely a personal one. Nothing the lecturer does can prevent a person willing to learn from doing so. The converse is also true, but the students willing to learn can certainly have their knowledge deepened and enriched through the adoption of student-centred pedagogies. Learners react positively when they are actively engaged by doing things in class and awarding credit for each assessment is generally effective in motivating engagement with the material.

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Author's bio

Declan Phillips, University of Limerick, Ireland

Declan Phillips is a senior lecturer at the University of Limerick (UL), Ireland. He spent five years in professional practice in the USA, specialising in geotechnical and structural engineering. He holds MSc and PhD degrees from the University of Dublin, is a registered professional engineer in the State of Pennsylvania and a Chartered Engineer in Ireland. Declan is responsible for designing UL's Problem Based Learning (PBL) programme in civil engineering which adopts a 'learning by doing' philosophy throughout the programme. He is a fellow of the American Society of Civil Engineers (ASCE) ExCEEd I & II programmes and is an Associate Editor for the ASCE Journal of Civil Engineering Education (formerly the Journal of Professional Issues in Engineering Education & Practice) and the Journal of Performance of Constructed Facilities. In 2008, he received a regional award for Teaching Excellence from the Shannon Consortium. He is a former member of the ISSMGE Technical Committee on Geo-Education (TC306) and was a member of the organising committee for the ISSMGE's international conference on Geo-engineering Education in 2012. Research interests include soil mechanics, instrumented field and laboratory testing, geoenvironmental aspects and reuse of municipal waste. He is also actively involved in research on student centred education and forensic engineering applications in teaching.

Engineering Geology and Soil Mechanics: The Need to Develop Educational Material that Captures their Relationship

C. Saroglou & M. Pantazidou

National Technical University of Athens, Zografou, Greece
saroglou@central.ntua.gr, mpanta@central.ntua.gr

ABSTRACT: The motivation for writing this paper was the scarcity in the geotechnical engineering literature of material that can be used in instruction to demonstrate how the knowledge of the genesis of the soil profile can be useful to geotechnical engineering. The lack of a dedicated map of soil deposits in Greece intensified the urgency to address this gap in the literature. The approach followed towards filling this gap was to start a campaign for the need to create such a map for educational purposes, to compile some guidelines that can complement information from boreholes, and to contrast two case studies with inhomogeneous vs homogeneous soil profiles.

Keywords: Soils, Engineering Geology, Soil Mechanics

1 Introduction

The investigation of the relationship between Engineering Geology and Soil Mechanics in this paper aims to highlight the geological knowledge that has decision value to geotechnical engineers and can be meaningful to soil mechanics students. Karl Terzaghi had an early fascination with the natural sciences and took several geology courses as a mechanical engineering student, before his inquisitive and restless mind finally settled to Civil Engineering where he could work in Engineering Geology, an involvement that turned out to be life-long and deep (Goodman, 1999). Perhaps, then, it is surprising that Terzaghi never completed his book on Engineering Geology, especially considering that he taught a course on the subject at Harvard, from which we have only class notes taken by two of his students in the 1950s (Goodman, 2003). Terzaghi had co-authored a book in German with the title Ingenieurgeologie (Redlich et al., 1929), but, according to Goodman (2003), “his contributions in that volume were mainly on the engineering side”. Contents of more recent engineering geology books (e.g. Goodman, 1993) and engineering geology courses in civil engineering curricula give the impression that the medium of interest is solely or primarily rock.

But when Karl Terzaghi (1961a) writes about the importance of Engineering Geology, he discusses first Soil Mechanics, or “Earthwork Engineering”, separately from Rock Engineering. As a general guideline for Earthwork Engineering, Terzaghi states that if the subsoil exploration reveals inhomogeneity, then the geological characteristics will give an indication of the uncertainties to be expected. Similar guidelines about what to expect are rarely found in the literature. In a related article, Terzaghi (1961b) gives an example by contrasting varved clays deposited in still water, which will be homogeneous in the horizontal direction, with clays in drowned valley deposits, which are likely to vary over short distances both in the horizontal and the vertical direction due to variations in the currents depositing them. This example by Terzaghi perhaps implies that it is more manageable to demonstrate the value of knowledge of the geological processes by contrasting cases, an approach which was adopted herein. Similar examples of contrasting behavior are also rarely found in the literature: one exception known to the authors is the example concerning slope characterization in river valleys by Abramson et al. (2002: p.236) who recommend closer boring spacing perpendicular to the valley axis compared to the spacing along the valley line.

The fact that such examples are continent-, country-, region- and location-specific shaped the scope of this paper, which includes: (1) compiling guidelines and presenting examples from regions with extensive areas of soil deposits and (2) focusing on Greece with the dual aim (2i) to produce a first map of Quaternary deposits, specifically its Holocene subset for a start and, with such a map as a frame, (2ii) to assemble existing information on major occurrences of recent soil deposits and identify information gaps to be addressed piecemeal by future work. Holocene deposits vary in thickness from a few meters to a couple of tenths of meters and are often the foundation material for engineering works such as bridges and buildings.

2 Soil deposit maps and engineering behavior

We hypothesize that the availability of country-wide soil deposit maps will encourage the study of their geological characteristics with the goal of offering a first estimate of their engineering behavior. At the very least, the availability of these maps will provide a place to start when building a soil profile and help anticipate soil type (e.g. sand, clay), soil deposit depth and degree of inhomogeneity.

The British Geological Survey (BGS) has produced a Quaternary map of the United Kingdom with a classification of deposits based on soil type, with some information on their depositional environment (BGS, 1977). More recently, BGS (Lawley and Garcia-Bajo, 2010) has compiled data suitable for producing a map of the location of the Quaternary-age surficial deposits across Great Britain (the paper includes only an indicative very small size, low-resolution such map), and created a model for their depth (which ranges from 1 m to 160 m, typically between 1 m and 20 m). In the Netherlands, similar borehole data for geological units dating back to the Cretaceous were incorporated in a model providing general information on the depositional environment (e.g. fluvial, glacial), the main type and the thickness of these units (Gunnink et al., 2013). All the Holocene deposits are represented as a single geological unit and the paper includes a map showing their areal extent. The authors have not located articles describing examples of how the maps that can be produced with these models either influenced selection of borehole locations or enriched the information provided by the borings.

It should be noted that herein we are interested in general-coverage maps, not in maps with soils of unusual behavior such as the quick clay deposits in Norway. (Naturally, the availability of geological maps in different countries is related to their specific needs.) Abramson et al. (2002) provide such a general-coverage map in their Figure 2.1, which shows a distribution of soils in the United States, distinguishing among alluvial, residual, loessial and glacial soils, referencing as a source the 1971 edition of the NAVFAC Design Manual 7. However, the 1986 edition of the NAVFAC Design Manual 7 (NAVFAC, 1986) does not include such a figure.

The same case study (an underground car park in London) discussed independently by Burland (2012) and de Freitas (2012) confirms the importance of a detailed knowledge of the soil profile– specifically, in this case, the existence of high permeability inclusions in clay. However, the two authors do not say anything about some geological characteristic that provided information about these higher permeability inclusions. In other words, from their discussion it is not apparent that certain geological characteristic(s) alerted them to the presence of these inclusions.

This is a good counter-example for what we are *not* after: the question being asked is not “what are the geological processes that resulted in the formation of these high permeability inclusions”? Instead we ask “what is the added value provided by the knowledge of the geological processes for the prediction of the engineering behavior of the soil formation?” Or, stated differently, “how does knowledge of the geological history of soils complement the information from soil borings?” Following Terzaghi’s advice, the answers offered focus on the expected heterogeneity of the soil deposits and its implications for geotechnical characterization.

3 Soil deposits in Greece

Greece is a mountainous country, to a percentage of 80% according to the criteria used by the European Union to define mountainous regions (Nordregio, 2004). Considering their frequency, there are clear incentives for the study of rock formations. On the positive side, the relative scarcity of soil deposits in Greece (compared to other countries) makes more manageable the undertaking of studying at least their major occurrences.

3.1 Map of soil deposits

The main Neogene and Quaternary sedimentary basins of Greece are sketched in Figure 1a (map re-drawn from original map by Mountrakis, 2010). Nine main basins are identified herein: 1) the Evros river basin, 2) the Nestos river basin, 3) the Strymonas river basin, 4) the Aliakmon, Loudias, Axios, Gallikos rivers-Thessaloniki basin, 5) the Florina-Vegoritis-Ptolemais basins, 6) the Larissa-Karditsa basins, 7) the Argos-Korinthos-Xylokastro basins, 8) the Pyrgos-Kyllini basins, and 9) the Iraklion basin in the island of Crete. The bulk of soil deposits are located in the basins shown in Figure 1a and correspond roughly to the areas depicted with green color in the slope map in Figure 1b. A crude estimate of the age distribution of soil deposits in Greece is that about 80% of all soils are Quaternary, of which 70% are Holocene.

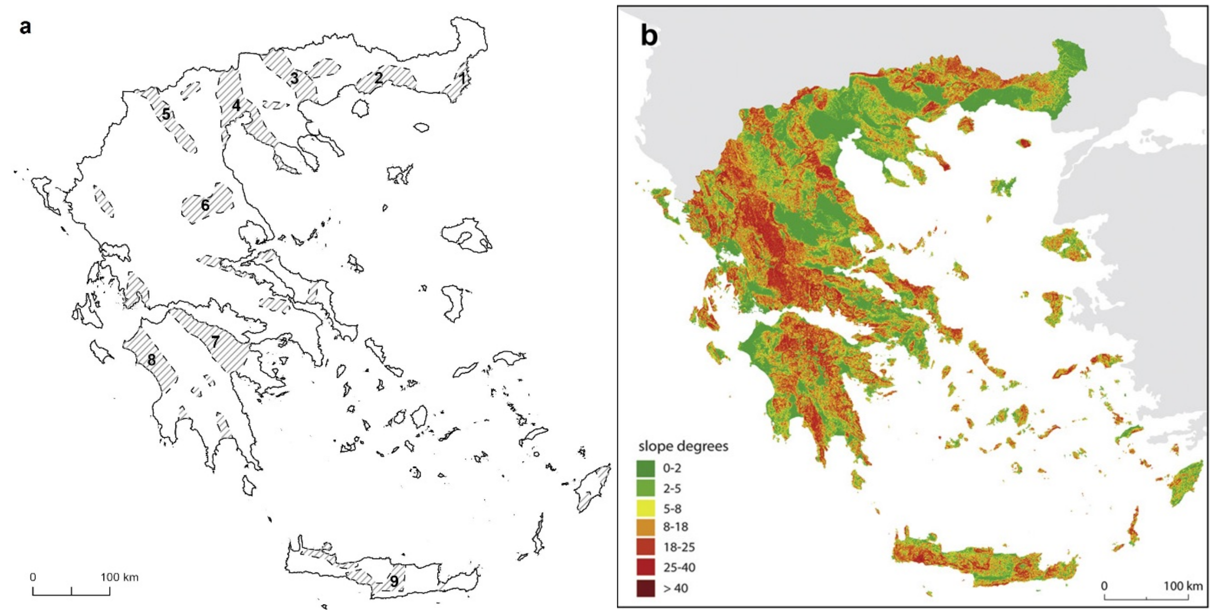

Figure 1. a) Main Neogene and Quaternary sedimentary basins of Greece (redrawn from Mountrakis, 2010), b) Slope map of Greece

Taking into account that the Neogene soil deposits fall mainly in the continuum from hard soils to soft rocks, in the present paper we have considered, as a start, only the Quaternary deposits and more specifically the Holocene subset of deposits encountered in Greece that are shown with green color in Figure 2. These soil deposits are primarily recent alluvial deposits encountered in valleys and plains. The map was produced in ArcGIS 9.2 (ESRI, 2006), based on data provided by the Hellenic Survey of Geology and Mineral Exploration (HSGME).

Figure 2 provides a good example of the different needs of professionals and educators. The basic geological maps of Greece (HSGME, 2015) have been available to practitioners and educators, for a fee, in 327 separate sheets covering all of Greece at a scale of 1:50,000, each sheet corresponding to an area of 18 by 22 kilometers. In principle, information could be extracted from these sheets to create a map like the one in Figure 2. However, to the authors' knowledge, there has not been an effort to produce, on a larger scale, a dedicated map showing only the occurrences of soil deposits. Perhaps such a large-scale map is of little use to the practitioner. But it is very useful for an educator in search of material suitable to motivate beginners (students).

The Quaternary (Holocene) deposits in Greece are mainly alluvial deposits, with some coastal deposits and, more seldom, lagoon and aeolian deposits. In general, soil deposits can be characterized as follows:

- Soil deposits with predominantly fine-grained particles (e.g. Case B in Section 4.2).
- Soil deposits with predominantly coarse-grained particles (Greece lacks deposits of significant extent of this type because their formation is connected with long periods of deposition in basins surrounded by relatively uniform bedrock, conditions that rarely exist in Greece).
- Soil deposits with mixed particle size, encountered usually in layers but with lateral variability (e.g. Case A in Section 4.1).

Figure 2. Outcrop of the Holocene subset of the Quaternary soil deposits in Greece (scale 1:1,000,000), (i) Aliakmon, Loudias, Axios, Gallikos rivers area and (ii) Sperchios river area

3.2 An attempt to put together some guidelines, both general and Greece-specific

After discussions with colleagues knowledgeable in geology, the second author has formed the impression that the guidelines on how geology can inform soil mechanics appear to belong in an "oral tradition": when the question of references arises, none is offered. If this impression is wrong, it is hoped that the present article will offer an incentive for these references to be identified and for suitable examples to be put forth. For the time being, the following compilation of general guidelines is provided:

- Lake sediments and sea sediments tend to be fine grained and, compared with river sediments, more uniform.
- River sediments in flat valleys, e.g. the area of tributaries of main rivers in central Macedonia (Aliakmon, Loudias, Axios, Gallikos), are more uniform and fine-grained compared with river sediments deposited by rivers with steep gradients, e.g. Sperchios river, see Figure 2, areas (i) and (ii), respectively.
- Sediments at the shoreline of lakes are less uniform (i.e. more like river sediments) compared with lake sediments further away from the shoreline.
- The heterogeneity and lateral variation of the recent sedimentary deposits in Greece is mainly due to the high tectonic activity in the country; the resulting heterogeneity of the parent bedrock formations produces different soil types.
- The tectonic activity is responsible for the continuing uplift of large parts in the country, which created a varied morphology (abrupt changes in the terrain), thus allowing for high-energy depositional

environments. Additionally, Quaternary deposits with greater thickness are encountered near structural zones, i.e. active faults, where tectonic movement results in fault escarpments producing degraded material.

• Paleo-morphology features, like buried valleys or paleo-deltas, may result in large thickness of Quaternary deposits. Tectonic activity is associated with higher probability for the occurrence of buried valleys, which, however, may have been formed from non-tectonic processes, e.g. from a landslide that covered river sediments.

4 Case studies

This section contrasts two case studies, Case A (Section 4.1) and Case B (Section 4.2) involving mainly alluvial soils, at the locations shown in Figure 2. The case studies were selected as examples primarily of the relationship between the geological processes and the required information from boreholes and, secondarily, of anticipating the engineering behavior of the soil formations. The two case studies have different soil profiles. The first is a heterogeneous profile consisting of clays, silts and sands of fluvial origin and the second is a homogeneous profile consisting of fluvial fine-grained material.

According to the regulations of the Greek State, the design of engineering works is performed in different stages: a) preliminary design, for which an initial, usually limited, site investigation is performed, and b) final design, for which a more detailed investigation is executed that allows the designer to optimize the engineering requirements based on a more accurate ground model. In some cases, the preliminary investigation stage is skipped and only the final design is executed. The geotechnical investigation of Case A was at the stage of preliminary design. The design for Case B was performed in a single stage, i.e. the final stage.

4.1 Case A: Kyllini

Case A is an area along the new National Highway connecting Patras, Kyllini and Pyrgos in western Peloponnese, at the location of a future roadway bridge overpassing the railway line (coordinates 37°54'59.83"N, 21°16'0.55"E). The length of the concrete bridge is 310 m. It will be founded on nine (9) piers and be constructed with the cantilever method. As the site investigation in Case A was at a preliminary stage, the number of boreholes was limited only to the location of some of the piers, in order to make a first assessment of the foundation conditions. A final design stage would follow with additional ground investigation, before finalizing the structural design of the bridge. However, due to delays in the funding of the project, this stage has not been executed and the construction of the bridge has not started at the time of the writing of this article.

4.1.1 Geological background

The area of Case A is characterized by the alluvial Quaternary deposits of Peneus River (“Pinios” in Greek), the 3rd longest river in Peloponnese, which discharges into the sea in the broader Kyllini area, as shown in Figure 3. The area is characterized by Holocene terrestrial (i.e. including ground surface runoff and river flow) and torrential clayey and sandy deposits [geological map of Greece, scale 1:50,000, sheets Amalias (HSGME, 1977a) and Nea Manolas (HSGME, 1977b); Maroukian et al., 2000]. According to the Amalias sheet (HSGME, 1977a), the project area and a significant area around it are covered by “recent deposits: sands and grits in the area, sands and cobbles at the torrent beds”. The torrential clayey and sandy deposits represent the most extensive Quaternary alluvial deposits in the Peloponnese. Primarily responsible for the accumulation of these deposits is the Peneus River, originating in the Arcadian Mountains to the east and entering the Ionian Sea south of Cape Kyllini (Figure 3). However, the palaeo-delta of the Peneus River is believed to have been located north-west of Cape Kyllini (i.e. north of the present river bed), giving rise to a sequence of lagoons and marshes embedded in the prograding delta and fed by sediments from the uplands of the Elis administrative region. The area is one of the most seismically and tectonically active regions in Greece, with a great number of changes during the morphogenetic events taking place mainly during the Quaternary period. Hence, a lot of variability is expected in the sediments of the Peneus River. The geology of the area is presented in Figure 3, based on the work of Haenssler et al. (2014).

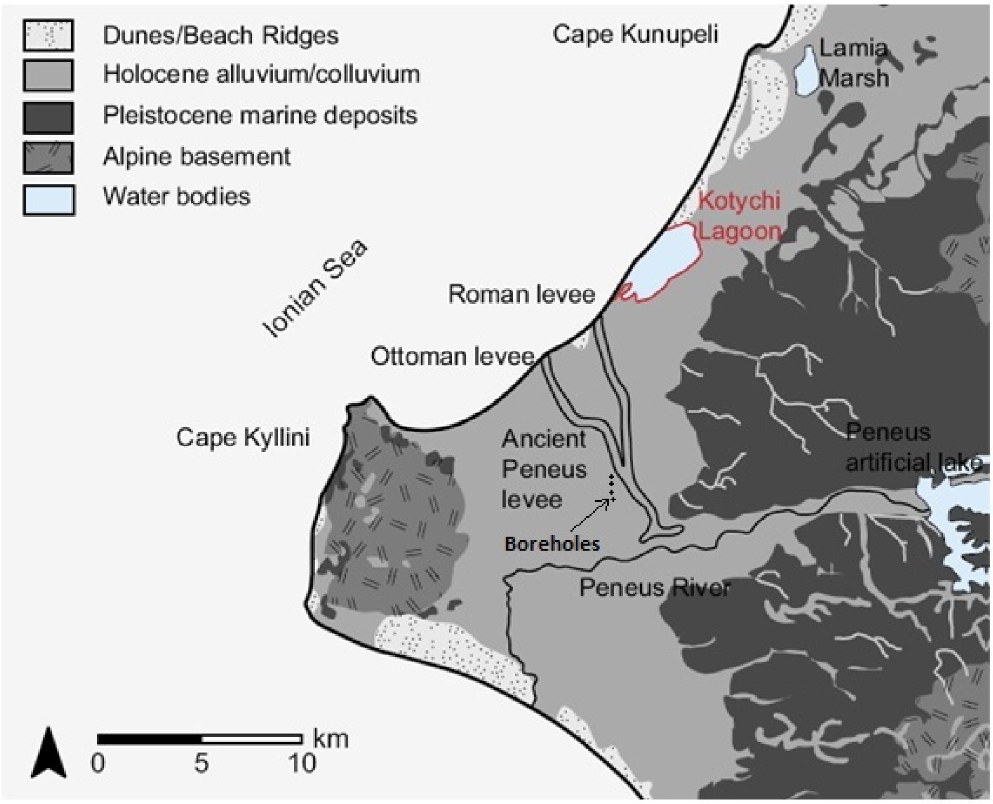

Figure 3. Outcrop Geology of the wider area of Case A, according to Haenssler et al. (2014) (figure published under Creative Commons Attribution 4.0 License)

4.1.2 Geotechnical investigation

A geotechnical investigation campaign was executed in order to perform the preliminary geotechnical design of the bridge foundation. At this preliminary stage, it consisted of only five (5) sampling boreholes up to a depth of 40 m below ground level (GL), located in the vicinity of five from the nine peers of the bridge. Figure 4 summarizes the findings from the five boreholes (BH1 to BH5), which were spaced about 85 m apart: the borehole findings show that the ground consists of a very heterogeneous profile in both the horizontal and vertical directions. A sequence of clays, sands and silts was encountered up to a depth of 35 m, overlying a horizon of dense sands. The lateral variability in the area is due to the deposition of different types of materials (fine and coarse), which belong to the fluvial and paleo-deltaic system of Peneus river. The following units (layers) were encountered:

- **Unit I**. Layers of light brown, low-medium plasticity, moderately stiff-stiff clays (CL) with intercalations of silty clays (CL-ML) to low compressibility sandy silts (ML), $N_{SPTmean}$ = 11.

- **Unit II**. Light brown, poorly sorted, dense sands (SP), $N_{SPTmean}$ = 50.

- **Unit III**. Clay of low to medium plasticity (CL): in some locations intercalations of silty clay (CL-ML) and low to medium plasticity silt (ML) are encountered, $N_{SPTmean}$ = 17.

- **Unit IV**. Stiff, medium plasticity clays (CL)-very stiff, high plasticity clays (CH), $N_{SPTmean}$ = 25.

- **Unit V**. Grey, poorly sorted, dense sand (SP) to silty sand (SM), $N_{SPTmean}$ = refusal.

Unit II (sands) was present only in two of the five boreholes (BH1, BH3) and the thickness of most units (especially Unit III and IV) varied significantly, resulting in lateral variations of the profile. This variation is characteristic for fluvial depositional systems, where different soil particles are found in the inner and outer banks of the river. The fact that the area of Case A is also very close to the paleo-delta, also explains the primarily fine character of the soil deposits at greater depth (Unit I, III and IV). Unit V is most probably the Pleistocene marine deposits underlying the Holocene fluvial deposits (Unit I to IV).

With the exception of the sandy layer consistently appearing at depth varying from 35 m to 38 m (Unit V), the area of Case A is characterized by significant heterogeneity with layers of varying thickness and lateral transitions. Thus, it was not possible to construct a geotechnical profile for the area, but only to have knowledge of the ground conditions at the vicinity of each borehole.

Following the ground investigation it was determined that the higher bearing capacity layer, Unit V consisting of sands, is located at a significant depth of approximately 35 m and, therefore, it was decided that the foundation would be designed with friction piles within the first three layers (Units I, II and III) reaching a depth of 20 m.

The understanding of the ground profile for the foundation conditions of the remaining four (4) piers would require either a detailed study and interpretation of the geology of the site or the execution of additional boreholes. As already mentioned, at the time of the writing of this article, the project has been halted for some time, so it is not known how the geotechnical investigation will proceed.

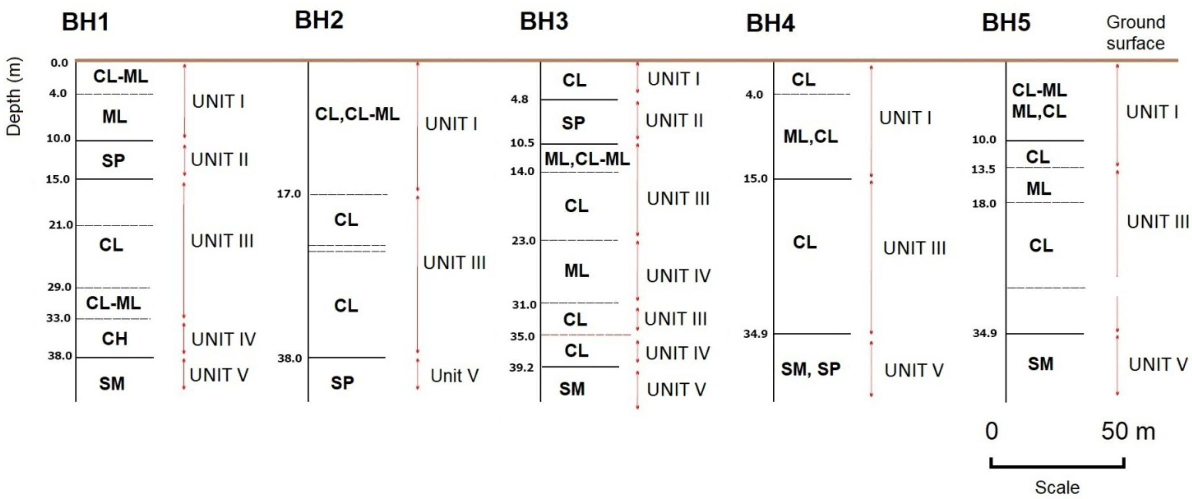

Figure 4. Ground profile in the area of the foundation of the bridge in Case A (adapted from General Consulting Ltd, 2003)

4.2 Case B: Evros

Case B is an area at the border of Greece with Turkey (called Peplos) along which the Evros River flows (coordinates 40°54'49.37''N, 26°16'35.03'' E). In this area an irrigation network of open canals was planned and the geotechnical design was required mainly for the foundation of the pumping station. The study area has a horse-shoe shape delineated with a yellow line in Figure 5. The total surface of the area that will be irrigated using water from the Evros River is 74 km^2. The irrigation is achieved through a pumping station that removes water from the river and transfers it first to a storage tank and then to the irrigation canals. The main canals run in the north-south direction, while secondary canals reach the entire irrigated area. The canals will be lined with precast concrete elements.

4.2.1 Geological background

Geologically, the area is characterized by the fluvial deposits of the Evros River and the deltaic sediments near its banks. The north part of the Case B area is dominated by silts, deposited nearby an earlier location of the river bed, which cut through the land protrusion near the center of Figure 5, i.e. the location of the project. The south part of the Case B area is dominated by clayey sands, which are associated with the current, meandering river bed and slower flow velocities that allow sand to settle. Based on Kanellopoulos et al. (2008), the depositional environment in the region is characterized by consistently low energy, thus mainly fine grained soils are expected, of uniform consistency with depth. The deposits originate from the erosion and washing out of older Quaternary formations and are deposited mostly during flooding periods.

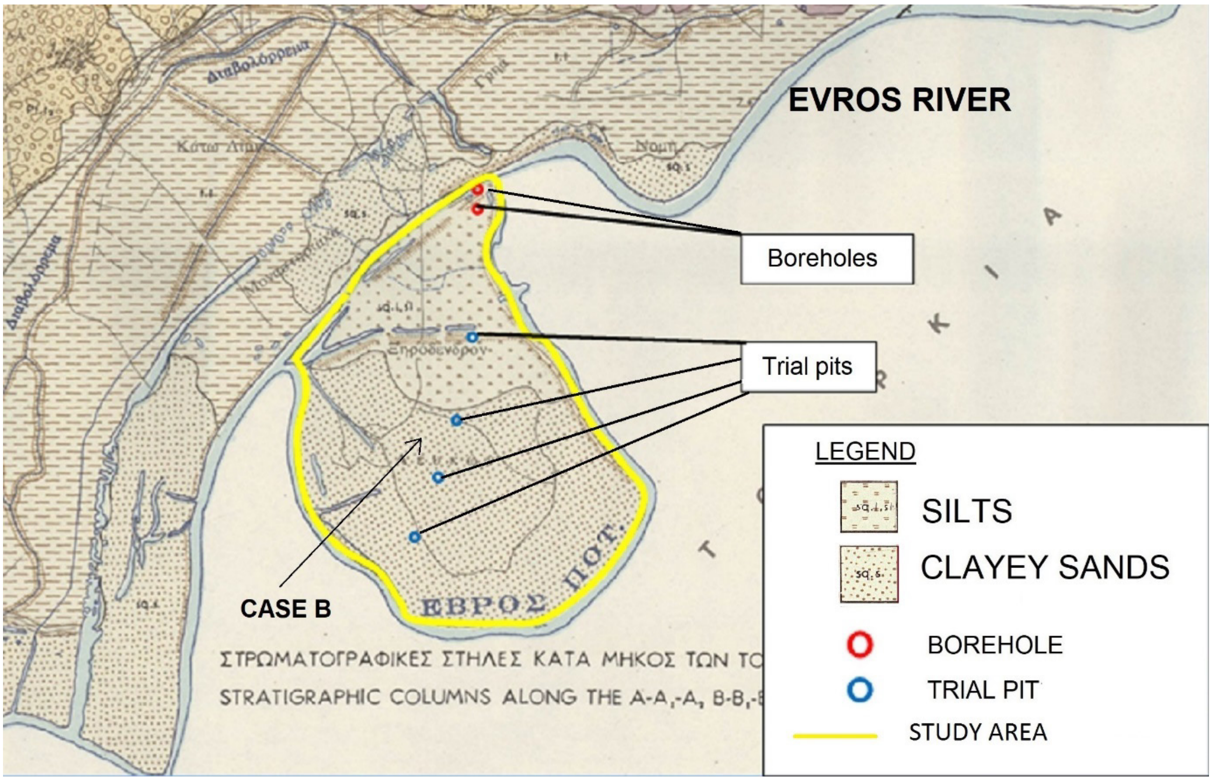

Figure 5. Geological map of Case B area at scale 1:50,000 (HSGME, 1980)

4.2.2 Geotechnical investigation

A geotechnical investigation campaign was executed consisting of two (2) sampling boreholes, located 150 meters apart, to a depth of 20 m below ground level, in order to design the foundation of the pumping station and the storage tank. In addition, four trial pits were excavated to a depth of 2 meters to design the irrigation canals. As already mentioned, the geotechnical investigation fell within the scope of the final design of the project.

Based on the findings of the boreholes, it was evident that the ground profile was homogeneous, with practically no variation in the types of soils. The following units (layers) were encountered:

Unit I (brown-grey) and **Unit II** (grey), 0 to 8m, soft clay of low plasticity (CL) $N_{SPT\ mean}$ = 4.

Unit III, 8, to 20m, grey stiff clay of low plasticity (CL) $N_{SPT\ mean}$ = 13.

The geological history of the area and the information from the boreholes both point to a uniform ground profile, consisting primarily of fine sediments. Moreover, as these sediments are relatively recent, it is anticipated that the soil shear strength and stiffness increase linearly with depth.

5 Concluding remarks

The motivation to put together this paper was to claim a space for soils within engineering geology and sketch suitable educational material. In order to claim a space for Greek soils in particular, the authors sought the information necessary for depicting the areal extent of the recent Quaternary (Holocene) deposits encountered throughout Greece, as a first step towards producing a soil deposit map for Greece. The paper discussed in the form of general guidelines how the knowledge of the geological setting and depositional conditions of a specific area helps anticipate some general features of the ground profile. At the very least, the depositional history can guide us to expect homogeneous or heterogeneous soils.

The knowledge of local geological conditions and history of a specific site can assist in understanding the complexity of the ground profile and therefore provide vital information to determine the appropriate geotechnical investigation campaign. When significant lateral and vertical variation of the soil profile is expected, it is advisable not only to increase the number of boreholes but also perform a detailed geological study to build a more accurate ground model. The type of investigation of course is also determined by the design stage of the project, whether preliminary or final.

Two case studies, A and B, were selected to further demonstrate with examples the influence of the depositional environment on the expected heterogeneity. The sediments in both cases were alluvial, but they differed in terms of depositional energy and tectonic activity, which where both higher in Case A, resulting in variations in morphology and in the consistency of the parent bedrocks. In Case A, the ground profile was very variable due to sedimentation in a highly active tectonic area. In Case B, the ground profile originated from deltaic deposits in a relatively low-energy depositional environment, thus the deposits were homogeneous, as expected in such environments. The implications of these two contrasting profiles for the design of a ground investigation campaign is that complicated profiles, such as that in Case A, require a larger number of boreholes in order to determine the design profile for a sizeable infrastructure project, such as a bridge foundation.

In summary, the authors attempted to capture the relationship between Engineering Geology with Soil Mechanics through a few suggested general guidelines and two case studies. Their ultimate goal is to create a common frame, which the engineering geology and geotechnical engineering communities can modify and expand upon.

Acknowledgements

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Authors' bios

Charalampos Saroglou, National Technical University of Athens, Greece

Charalampos Saroglou is a Teaching and Research Associate at the School of Civil Engineering, National Technical University of Athens (NTUA) and a Visiting Lecturer at the School of Earth Sciences, in the University of Leeds. He holds an undergraduate degree in Geology from the University of Athens, graduate degrees in Engineering Geology from Imperial College and Design and Construction of Underground Works from NTUA and a Ph.D. in Geotechnics from NTUA. In 2014-2016 he worked as a Lecturer at the Department of Civil and Environmental Engineering, Imperial College. For his Ph.D. work, he has received a Research Prize from the Academy of Athens. He was also awarded the Richard Wolters Prize by IAEG and a visiting academic Scholarship from the Chinese Academy of Sciences. His research interests include the engineering behavior of soils and rocks, engineering geology for infrastructure works, rock slope stability and mitigation of geohazards. He has authored 80 scientific papers published in journals and conference proceedings. He is member of the IAEG (Commission C38), the ISSMGE (Joint Technical Committee JTC1) and the ISRM.

Marina Pantazidou, National Technical University of Athens, Greece

Marina Pantazidou is an associate professor at the National Technical University of Athens (NTUA). Before joining NTUA in 2001, she worked in geoenvironmental consulting in the US (1991-1993) and was an assistant professor at Carnegie Mellon University (1994-2000). In 2000-2001, she was a visiting scholar at the Graduate School of Education at UC Berkeley. Her research interests include (1) environmental geotechnics and (2) engineering education. She has authored 90 journal and conference papers, about a third of which on education topics, and has edited two special journal issues on geotechnical engineering education. She is a member of the American Society of Engineering Education, the Hellenic Society of Soil Mechanics and Geotechnical Engineering (Secretary General, 2012-2015, and Board Member, 2015-present), and the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). She has been a core member of ISSMGE's Technical Committee for Geo-engineering Education (TC 306) since 2010, Vice Chair for the 2013-2017 term, and Chair for the 2017-2021 term.

Open Resource Educational Material

Producing a Case-Study Webinar for Geotechnical Engineering Education

M. Calvello

University of Salerno, Fisciano – SA, Italy
mcalvello@unisa.it

ABSTRACT: The paper describes the phases needed to produce and promote a webinar aimed at presenting a geotechnical case-study, to be used by geotechnical instructors of engineering undergraduate courses as supplementary educational material for their students. The case-study webinar discussed herein deals with the consolidation process in fine-grained soils associated with the realisation of a well monitored test embankment, and it has been delivered by Carlo Viggiani, Emeritus Professor at the University of Naples Federico II in Italy. This paper addresses the process followed by the producer to support the presenter in the realisation of the webinar, i.e. to move from the webinar concept to its final realisation, including posting and promoting the material online as well as supporting follow-up initiatives. The paper is not addressing the educational purpose of the specific geotechnical aspects dealt with in the webinar.

Keywords: Webinar, Video lecture, Educational material

1 Introduction

The ISSMGE Technical Committee 306 on Geo-engineering education (TC306) focuses on the fundamentals of soil mechanics and geotechnical engineering, i.e. topics typically covered in undergraduate curricula. Its primary, but not exclusive, audience is currently active, past and future geotechnical engineering educators. In particular, as written in the terms of reference, the activities of TC306 aim at enriching the toolbox of geotechnical engineering instructors through: (i) debates on challenges of teaching fundamental concepts; (ii) recommendations for geotechnical curricula; (iii) reviews of resources for geotechnical laboratory classes, e-learning resources, other transferable/reusable geotechnical education material, and useful geotechnical engineering education references. The case-study webinar presented herein should be considered an educational resource that geotechnical engineering educators can add to their teaching toolbox. This initiative can also be considered as complying to one of the strategies suggested by Shulman (1993), i.e. teaching must be made visible through artifacts, to “put an end to pedagogical solitude".

2 Scope of work

The paper describes the phases needed to produce and promote a webinar aimed at presenting a geotechnical case-study, to be used by geotechnical instructors of engineering undergraduate courses as supplementary educational material for their students. The initiative was conducted by the author (from here onwards, the producer), with a mandate from the ISSMGE Technical Committee 306 “Geo-engineering education”, as a pilot project aimed at setting the stage for a series of such webinars. The main aims of geotechnical case-study webinars promoted by TC306 are: present classical geotechnical concepts to students by means of real world geotechnical engineering projects; produce and promote the use of open-access reusable geotechnical educational material.

The case-study webinar discussed herein deals with the consolidation process in fine-grained soils associated with the realisation of a well-monitored test embankment, and it has been delivered by Carlo Viggiani, Emeritus Professor at the University of Naples Federico II in Italy (from here onwards, the presenter). The title of the case study is “Porto Tolle test embankment - A full scale experiment on the consolidation of a thick clay layer”. The main reference is a scientific article published in Italian (Bilotta and Viggiani 1975).

3 The production phase

The production phase started at the end of 2017, with the choice of the case-study to be presented and the definition of the main geotechnical educational aims of the webinar, and finished at the end of 2018, with the publication of the webinar online. After the definition of the scope of the work, the time needed to complete the production of the webinar involved: collecting the case-study material and creating various drafts of the webinar (presenter tasks); refining the draft slides and audio commentaries (discussions between presenter and producer); refine the audio and video quality of the final slides of the webinar (producer tasks); create the final video and supporting material (producer tasks); time needed to identify appropriate online outlets for the webinar; and post the material on the web (producer tasks).

3.1 Selecting the tools for preparing and recording the presentation

The first major technical choice a producer and a presenter need to make when preparing a webinar is agreeing on the tools to adopt, i.e. identifying the main software to prepare and record the presentation. To this aim, a preliminary discussion was conducted to decide whether to record the presenter while talking, to later include this video in some parts of the webinar. The producer and the presenter soon agreed that this feature would have had very limited added-value for the potential viewers of the webinar. Therefore, they decided to spare themselves the many technical difficulties that the realisation and the use of such a recording would have implied. Moreover, they both shared the opinion that, in many cases, the simultaneous presence of such a recording, together with the content of technical slides (for instance, as a small inlet on a corner of the frame), is detrimental for the viewers, as it may decrease the attention they should pay, as instructed by the presenter, to other important parts of the frame.

Concerning the presentation, to minimise the added burden a recorded webinar poses to the presenter with respect to a typical live lecture, it was decided to adopt a presentation software that the presenter was already familiar with. The choice of the tool to use for this purpose fell to Microsoft PowerPoint, a very widely used software to prepare and deliver live presentations (the version used herein was PowerPoint 2010). This choice was possible because PowerPoint has also embedded features that allow a user to: seamlessly record the audio commentary and the animations while presenting; easily activate, at any given time during the presentation, the recording of the mouse movements when the presenter wants to use it as a pointer to draw the viewers’ attention to a part of a given slide. Although PowerPoint is a general-purpose presentation software not specifically designed to record webinars and it does not allow the combination of multiple audio and video tracks, it is relatively easy for the users to play, edit and export the presentation recordings after they are completed. Indeed, all the recorded audio tracks, animations, mouse movements, and adopted time intervals are saved in the same single file used for the slides (extension .PPTX). As a matter of fact, this single file is a compressed directory storing each element of the recorded presentation, slide by slide. For instance, the audio commentary is stored using a number of .WAV files equal to the number of slides, and the audio information is “attached” to the each slide so that if a user changes the recording of a given slide, the new audio track automatically replaces the old one. This characteristic can be profitably used if, after an initial recording of the entire presentation, one wants to change the recording of only a selected number of slides. The same principle holds for recorded audio tracks, animations and mouse/pointer movements. A negative side effect of breaking down the recorded audio in a number of separate audio tracks is that, whenever a presenter is talking during a transition between two slides, the final recorded audio ends up having a small break in the recorded voice in corresponding to that transition. Also in this case, however, post-recording editing is possible.

3.2 Defining the outline and the format of the presentation

An important issue discussed between the producer and the presenter at a very initial stage of the project was the proposed structure of the webinar. To this aim, the key points addressed were: format and style of slides, expected duration, and sections of the presentation. Straightforwardly, the 16:9 landscape format was identified as the most suitable format to adopt, whereas the choice of the style of the slides was discussed at some length. Starting from the "personal style" of a typical presentation by Prof. Viggiani (almost each professor has a preferred presentation style that he/she uses recurrently), we finally ended up with a purposefully-devised new style, after agreeing that slides intended to be used within a webinar needed a series of specific features, such as clearly readable fonts, relatively large font size, dark text on white background, consistent colour scheme, limited and consistent animation schemes. Assuming the text in the slides would have been mainly composed of headings, captions and brief sentences, 'Calibri' was selected as the single font to be used throughout the presentation because it is a standard, popular, general-purpose font with a good readability at all sizes. The sizes varied from 60pt for the large title slides to 28-40pt for most of the paragraphs and headings, with a minimum size of 14pt for legend items or text embedded in the figures. As most of the figures were to be derived from scanned versions of paper printouts in black and white, a white background was chosen, with the expectation that this would allow easier blending of the figures where they were to be combined with text. Accordingly, to maximise readability, dark blue was chosen as the main colour of the text, and red was selected as the secondary colour to be used to highlight specific words or sentences. Finally, it was agreed that the original black and white figures would be enriched, when needed, using coloured elements to highlight specific parts of the figure, such as data points or curves, with or without animations. In these cases, special attention was given to use a coherent set of colours and to consistently employ the same colour for the same element appearing in different slides, such as soil types.

Concerning the duration of the webinar, it was decided to set its length to less than 30 minutes, because a longer length would probably have limited its appeal to be used by other instructors in their classes. The possibility to subdivide the webinar in different videos was explored but then abandoned in favour of a compromise choice, with a clear subdivision of the presentation in sections within a single recording. It was decided that the sections to be adopted in this case were to be: the project, soil exploration, the test embankment, interpretation of results, lessons learned. It was decided that the different sections would be introduced by a standard format section title slide and a standard slide transition animation.

3.3 Preparing the slides

As already mentioned, the case study has been described in only one published article (Bilotta and Viggiani 1975), written in Italian and only available as a post-print. Moreover, given that both the engineering work addressed in this case study and the scientific article derived from it were more than 40 years old, the search for unpublished material from which to obtain additional data and higher quality figures and charts—at the time of the work available to the presenter—was unsuccessful. Therefore, the producer and the presenter agreed that an important part of the slides' preparation should involve editing the original black and white figures of the article to adapt them to the format of the slides described in the previous section. Figure 1 shows, as an example, the comparison between the original and edited figure showing the index properties of the soil.

The composition of the presentation has been essentially performed by the presenter. During this phase, the role of the producer was limited to ensuring that the slides would comply with the agreed format. To this aim, the producer has been in charge of: creating the initial page, with the logo of the ISSMGE and a reference to TC306; creating the section title slides; helping the presenter with the animations to be used throughout the presentation.

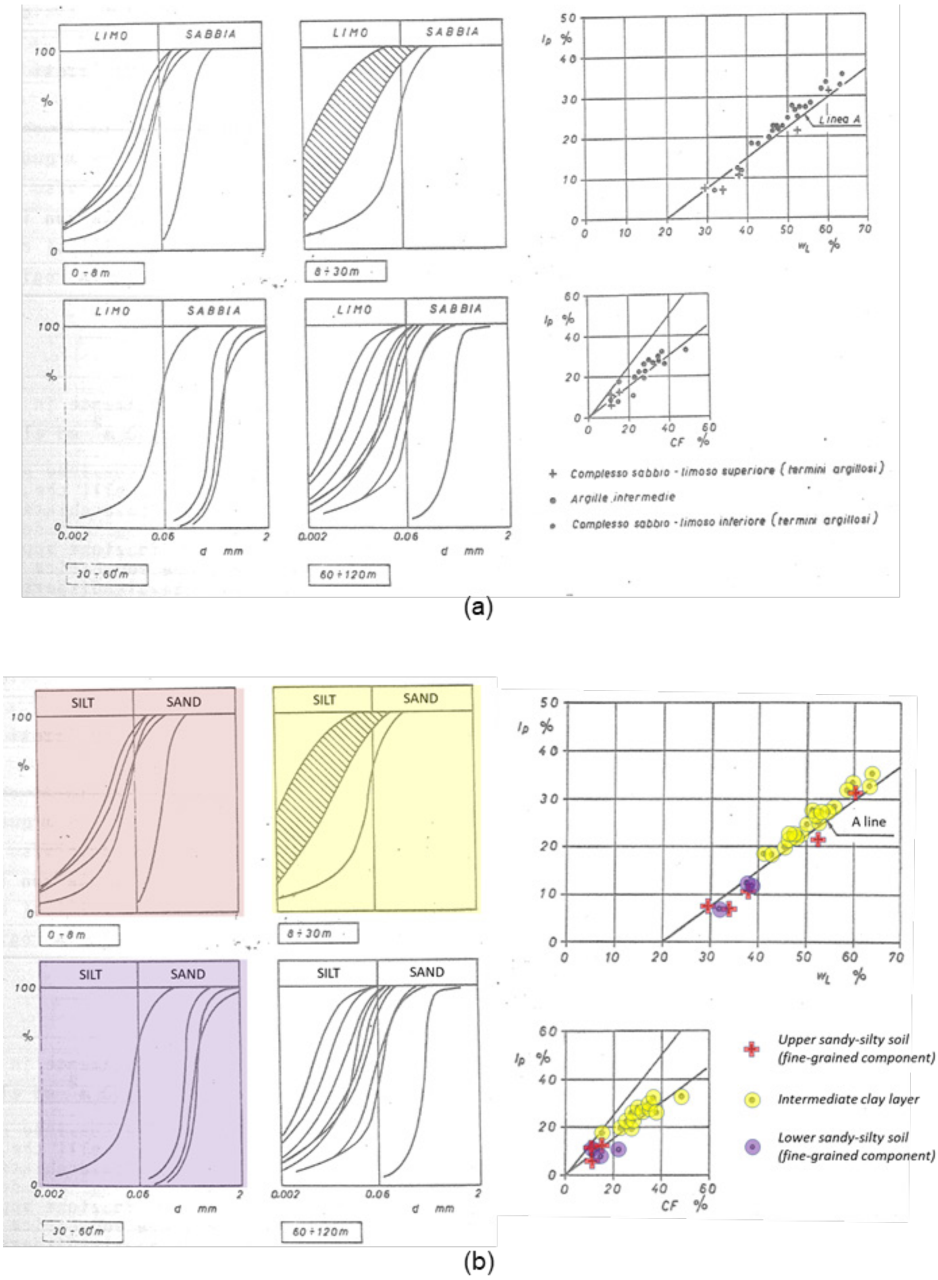


Figure 1. Example of (a) original figure from Bilotta and Viggiani (1975) and (b) modified figure used in slide 10 of the webinar

3.4 Recording and editing the audio-video material

Before a first complete draft of the presentation was available, the presenter recorded parts of it for quality checks of both the audio commentary and the visual aspects of the presentation, including animations and the use of the mouse as a pointer. Based on these recordings, a few corrections were performed to some parts of the presentation. Once the presenter and the producer agreed that the recording procedure was effectively working as it should have, and that there was no need to undertake a staged presentation, the final recording was performed by the presenter without the presence of the producer.

The final recording has been edited by the producer with the aim of improving: the quality of the recorded voice, the audio-video transition between some slides, the description of some charts by adding small animation-objects to the related slides. The quality of the audio recorded by the presenter, using the audio recording feature of PowerPoint, was improved by filtering out the existing ambient noise. To this aim, a freeware open-source software (Audacity version 2.1.0) was used. The procedure followed was relatively straightforward, because removing the ambient noise is one of the main features of any sound editing software. Initially, the original .WAV audio tracks were extracted from the presentation .PPTX file, by changing its extension to .ZIP and then opening it with a software opening .ZIP files (audio tracks are stored in the 'media' directory and they are sequentially named with the slide numbers they refer to, Figure 2). The original .WAV tracks were imported in the sound editing software, processed one by one using the standard settings of the noise filter feature (Figure 3), and then saved with the same names. The new audio files were then pasted in the .PPTX, to replace the old audio files. The improvements to the transition between some of the slides was done directly in PowerPoint. The fixes concerned mainly the length of the audio tracks, at times few seconds too long (i.e. useless wait for the next slide to appear) or too short (i.e. insufficient time at the end or at the beginning of a slide) in relation to the length of the slide. When an audio track needed to be shortened, it was selected and trimmed to the desired length (Figure 4a). When the length of the slide, which by default it is set equal to the length of the audio track, needed to be increased, the transition features were used to specify a known fixed duration for the slide (Figure 4b). The same features were also used to specify standard animations—in this case slide rotation—for the transition between the last slide of a webinar section and the title page of the next section. Improvements to some of the animations were also conducted directly in PowerPoint. When needed, particularly for slides with long duration comments or presenting charts, some new graphical elements—such as arrows or semi-transparent coloured shapes—were added and were set to appear at specific times of the slide. Finally, all the audio tracks and the other multimedia clips were compressed to reduce the size of the final file, using the PowerPoint feature called 'compress media'.

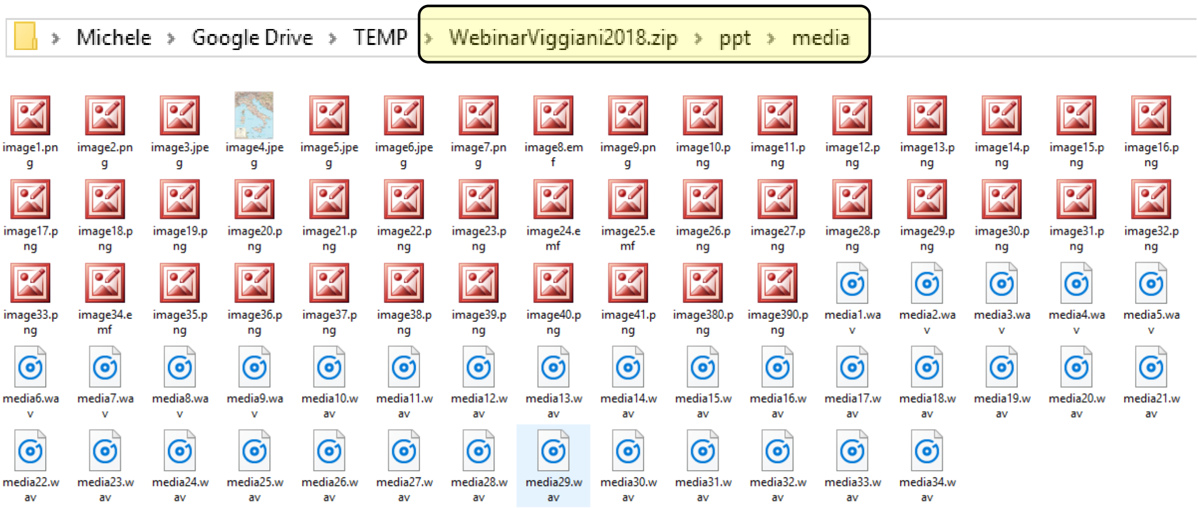
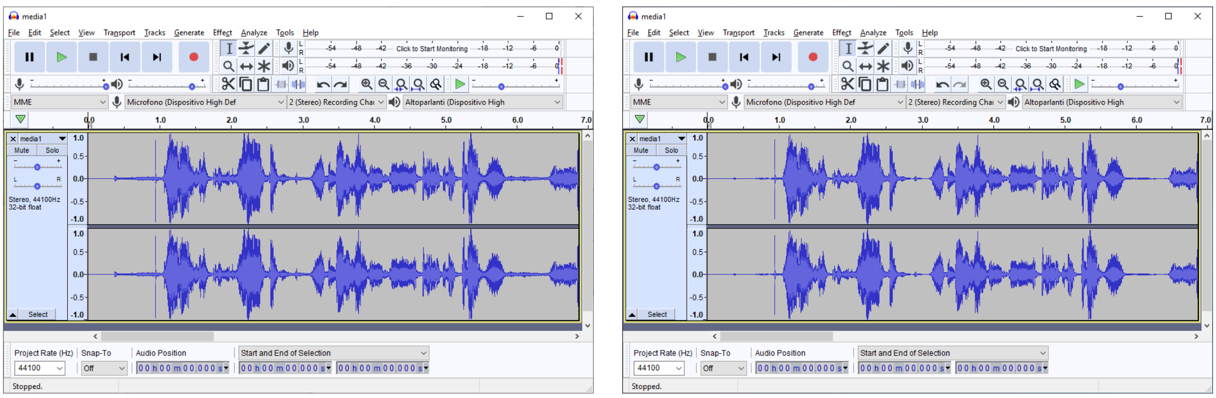
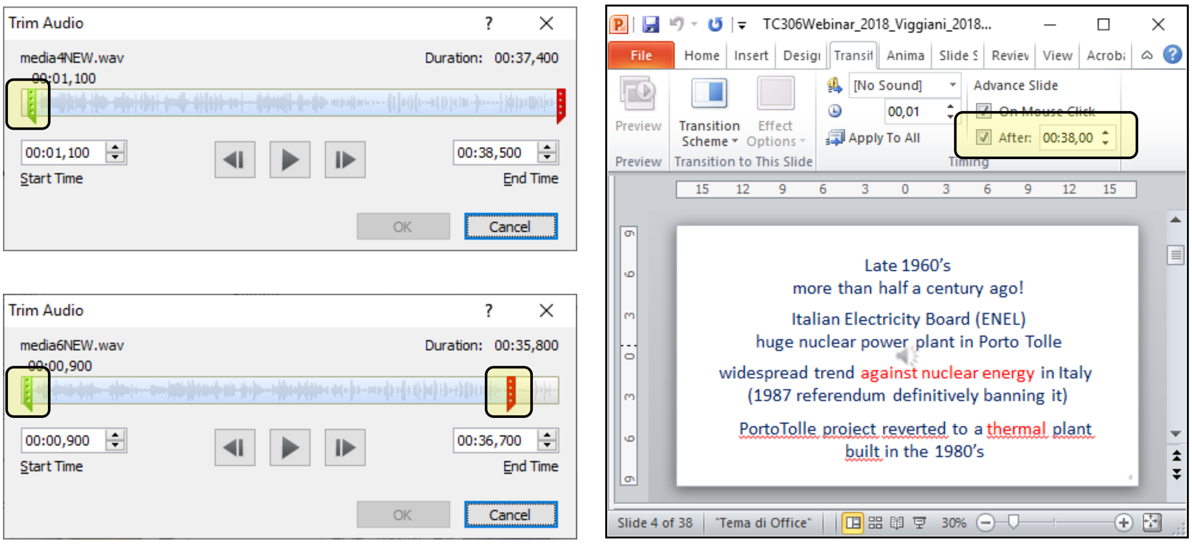


Figure 2. Files stored in the media directory of a PowerPoint .PPTX file, visible when the file is renamed employing a .ZIP extension



(a) (b)

Figure 3. Example of WAV file (a) before and (b) after noise reduction filtering



(a) (b)

Figure 4. Example of (a) shortened audio tracks and (b) set duration of slide

3.5 Creating the webinar videos and the slides to share

The final edited PowerPoint presentation of the case study was exported in the following formats: slide show presentation (.PPSX), slides' printouts (.PDF), internet-quality and high-quality video files (.WMV). All these formats are standard output options in PowerPoint. In the first and second case, one has to simply save the presentation as either a .PPSX file or a .PDF file. In the third case, one has to export the presentation using the 'create a video' feature. Before exporting, the user has the option to define the video settings preferences in terms of video quality, video size and video type. For the latter, depending of the version of PowerPoint used, the available video formats are .WMV and .MP4. In this case, the two exported videos were both .WMV files with a video frequency of 30 frames per second and the following frame sizes: 852x480 (for the internet-quality video) and 1280x720 (for the high-quality video).

3.6 Interviewing the presenter

The webinar is accompanied by an interview of the presenter Prof. Carlo Viggiani, conducted by the producer, mainly aimed at introducing the scope of the webinar. As Prof. Carlo Viggiani says in the initial part of the interview, "This case study has the advantage of being extremely simple, it deals with a simple mechanical scheme, one-dimensional consolidation, yet it highlights very well how theory is a model of reality, the real world is much more complex, and by measuring and observing, one can understand a lot of things". The video of the interview was recorded by means of a free recording App (OpenCamera), using the camera of a smartphone conveniently placed on a tripod set close to presenter and interviewer. The interview was conducted in Italian, the native language of both the presenter and the interviewer, and the audio was recorded by means of a double microphone connected to the smartphone. To create the final video of the interview, the recording was edited by the producer with the aim of adding a short audio-visual introductory track to the video and, most importantly, to place subtitles in the lower part of the frame translating into English the spoken Italian words. The video editing was conducted on a Mac laptop using the software iMovie by Apple.

4 On-line deployment and dissemination

The case-study webinar "Porto Tolle test embankment - A full scale experiment on the consolidation of a thick clay layer" delivered by Prof. Carlo Viggiani is, as stated above, the first of a series of case-study webinars that TC306 intends to produce. Therefore, TC306 institutional web outlets were used to post online the video of the webinar and the other material related to it. The web portal of TC306 is hosted by ISSMGE at: https://www.issmge.org/committees/technical-committees/impact-on-society/geo-education. As written there, the main dissemination venues include: 1) a web repository and forum for discussions on the GeoWorld website; 2) online access to proceedings of the TC306 conferences through the ISSMGE online Library; 3) a series of "case-study webinars" hosted on a YouTube channel.

The TC306 YouTube channel (https://www.youtube.com/channel/UC9WyOZWCbxPCkxQv7ANxEkw) was created to host this first case-study webinar and the interview introducing it. At the moment it only features the following two videos:

- TC306 case-study webinar by Prof. Carlo Viggiani (October 2018)
  https://www.youtube.com/watch?v=hWpyswdglBk
- Interview with Prof. Carlo Viggiani (by Michele Calvello)
  https://www.youtube.com/watch?v=EPEDepTWTD8

As written in the description of the webinar on YouTube, the slides of the presentation are available for download on the TC306 GeoWorld repository at: https://www.mygeoworld.com/file/139609/tc306-case-study-webinar-by-prof-carlo-viggiani-october-2018.

The presence of the case-study webinar online was advertised using the ISSMGE news section (https://www.issmge.org/news/prof-carlo-viggiani-delivered-the-first-tc306-case-study-webinar), and in a discussion topic on the GeoWorld TC306 group page (https://www.mygeoworld.com/groups/geo-engineering-education-tc306/discussions/case-study-webinar-by-prof-carlo-viggiani-october-2018).

5 Follow-up

The TC306 "Webinars & eLearning" task force is planning to distribute, along with each produced case-study webinar, a set of peer-reviewed annotations, a sort of 'Notes for Instructors', augmenting the webinar with additional material (e.g. clarifications, questions for the students, additional comments on the content of the slides) to be used during class discussion, for instance in a scenario where students are asked to watch the video before class. With this aim in mind, after the webinar delivered by Prof. Carlo Viggiani was posted online, the producer invited all TC306 members to watch the webinar and comment on it, considering a teacher's point of view and assuming that they would have wanted to use the case study in their own course. In particular, committee members were asked to think of clarification questions they would have liked to have an answer from the webinar presenter. Not many answers were received, yet the comments were nevertheless compiled and differentiated by categories as follows: request for clarification, request for supplementary material, suggested annotations, suggestions for teachers proposing the webinar in their classes, questions for students watching the webinar. The intention is to pass the annotated material to the presenter, asking him to provide replies to the different questions and requests, and then publish both the comments and the presenter's replies online, alongside with the webinar. Up to now, however, the compiled comments and requests have not been yet passed to the presenter. As a final remark on this issue, it is worth highlighting that, among the requests for clarifications received, perhaps the most important one is the wish to extend the final part summarising the main lessons learned. This indeed would help both teachers to better fit the case study in their courses and students to retain the most important learning messages highlighted by the case study.

Another follow-up initiative was promoted by the TC306 Chair, Prof. Marina Pantazidou. She prepared a problem inspired by the case study webinar, and she already used it within a written exam in her Soil Mechanics course at the National Technical University of Athens, Greece. Of course, the significance of this initiative does not simply lie on the webinar-inspired newly created exam problem for a single course, but on the overarching aim of having such homework/exam problems inspired by case-study webinars—together with detailed solutions—to provide incentives to other instructors to pay attention to and use the webinars in their courses. To this aim, the assignment has been posted on the TC306 GeoWorld repository as a PDF file (https://www.mygeoworld.com/file/139634/tc306-case-study-webinar-by-prof-carlo-viggiani-assignment-for-students-october-2019) and explicitly mentioned in the description of the Webinar on YouTube.

6 Concluding remarks

The webinar initiative presented herein should be seen as a pilot project for further case-study webinars to be produced by the ISSMGE Technical Committee on Geo-engineering education. The main aim of the article has thus been to describe, with an adequate level of detail, the work that a producer must carry out to help a presenter in preparing and delivering a webinar. In particular, to provide guidance for similar future endeavours, the paper included the detailed presentation of all the technical aspects associated with recording and creating the audio-video material and the supporting files for the webinar. To this aim, the paper identified and described the following main tasks: selecting the tools for preparing and recording the presentation; defining the outline and the format of the presentation; preparing the slides; recording and editing the audio-video material; creating the webinar videos and the slides to share.

It is worth highlighting herein some of the lessons learned during the production process of this webinar that can be proposed as general advice. The time commitment involved in the process must not be underestimated. Indeed, one must not forget that almost always (like in the case described) both the producer and the presenter work pro bono and that the commitment for the webinar tasks may end up having a low priority status in their work agenda for long periods of time; and it should also be considered that a webinar is surely a valid dissemination product but not a scientific product that can be easily used for career progress in Universities. The presenter and the producer must be familiar with the tools to be used to prepare and record the webinar. In this case, the choice to use a presentation software well known to both presenter and producer helped significantly in all the tasks requiring interaction between the two individuals. Setting a date for a staged presentation to be recorded, with the presence of the producer, may help reduce the burden on the presenter for delivering a first complete draft of the webinar. This was not the choice adopted in this case. Yet, in retrospect, it could have saved some time with the production process, also considering that the tool adopted to record the presentation easily allows for re-recordings single slides aimed at substituting parts of the staged presentation that do not comply with the required standards.

In the descriptions and discussions throughout the paper, the roles of presenter and producer have been clearly differentiated. However, it is worth highlighting that presenter and producer do not necessarily need to be distinct persons. Indeed, this article may be profitably used as a reference for presenters wanting or needing to produce their own webinar.

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Author’s bio

Michele Calvello, University of Salerno, Italy

Michele Calvello is associate professor in geotechnical engineering at the University of Salerno (Italy), where he currently teaches “soil mechanics” and “landslide risk”. He graduated with honours in civil engineering from Università della Basilicata (Italy) in 1997, and he earned a PhD degree from Northwestern University (USA) in 2002. His main research interests are focused on the engineering analysis of geotechnical boundary value problems and on the analysis and management of landslide risk, with special attention devoted to the following inter-disciplinary topics: early warning systems, landslide zoning, risk perception, risk education and community resilience. He is member of the Editorial Board of the scientific journals “Rivista Italiana di Geotecnica” and “Geoenvironmental Disasters“. He is the Coordinator of the LARAM School, an International School for PhD students on “LAndslide Risk Assessment and Mitigation” and the Secretary of ISSMGE TC-306 “Geo-Engineering Education”.

Teaching the Big Ideas of the Disciplines: Online Educational Material Accessible to Everyone for Soil Mechanics' Effective Stress

M. Pantazidou

National Technical University of Athens, Zografou, Greece
mpanta@central.ntua.gr

ABSTRACT: This paper claims that there is a missing type of knowledge that concerns education in all disciplines and belongs in the broader category "pedagogical content knowledge". In order to describe this missing knowledge and give an example, the paper first asks three questions and provides the respective answers: (1) Q: "what is worth being taught to everyone" – A: "the big ideas of the disciplines", (2) Q: "how to motivate the study of a big idea" – "with an essential question, phrased in everyday language" and (3) Q: "how to dress a big idea" – A: "with a lesson accessible to everyone", where "everyone" herein refers to an audience that includes high school students, university students (the main audience) and adults enjoying learning on the internet. In Soil Mechanics, "effective stress" is indisputably a big idea, and the essential question that aims to uncover it is phrased as follows: "what happens when soil compresses". The paper considers resources available to instructors developing online educational material, describes the methodological influences and the approach followed to create an hour-long modular video-lesson that answers the essential question phrased, and discusses comments made by reviewers of the video-lesson and the modifications resulting from these comments.

Keywords: pedagogical content knowledge, conceptual knowledge, design of educational material, geotechnical engineering instruction

1 Introducing the need to identify big ideas in the disciplines

The ultimate claim of this paper is that we need to identify and bring to the public light the core of each discipline, which includes its big ideas. This knowledge exists in a diffused state within the disciplines but, because it requires a concerted effort to give it shape, for practical purposes it is missing. Arguing for the need to somehow condense or distill the disciplines is not a new idea. It reappears periodically, for purposes such as enriching the general education component of tertiary education (Phenix, 1964), creating a unifying multidisciplinary foundation for Science, Technology and Society Studies (Kline, 1995) or better communication among the disciplines (Pantazidou & Nair, 2001).

The present study reintroduces the discipline distillation idea by searching for elements of the core of a thematic field with the help of the question "what is worth being taught to everyone from a thematic field". It differs from the previous conceptions of condensed knowledge in that it considers as main audience for the answer the university students in this *same* thematic field. The core of a thematic field can be identified with fidelity by efforts internal to the thematic field (i.e. not from external disciplines): for example, what belongs in the core of Physics is determined by physics experts, not from experts in the History or Philosophy of Science. This approach can ensure that the identified core of a discipline will have value for the discipline itself, not only for other disciplines or the wider public. At the same time, the involvement of experts with research skills in the Social Sciences and in the Humanities will endow the distillation undertaking with robust methodology and with interdisciplinary linkages helpful for its dissemination.

The broader endeavor motivating the present article seeks to give shape to the overlap between two largely missing bodies of knowledge: (i) the distillates of the disciplines previously discussed and (ii) the category of knowledge introduced in the education literature by Shulman (1986) with the term

"Pedagogical Content Knowledge", also known in Education with its acronym, PCK. In essence, Shulman (1986) argues for the necessity to build a supplementary body of knowledge for every thematic field X: the pedagogical knowledge of X. This is a foundational realization, which entails a difference between content knowledge (e.g. knowing how to do Mathematics) and pedagogical content knowledge (e.g. knowing how to teach specific topics in Mathematics to specific audiences). Shulman names components of this body of knowledge ("the most powerful analogies, illustrations, examples, explanations and demonstrations", "understanding of what makes the learning of specific topics easy or difficult") but does not specify who could produce and record this knowledge. Most instructors carry out parts of the task described by Shulman (1986) for their own teaching, and a few do it systematically and publish about it, but typically for topics taught at early stages of education (e.g. Lampert, 1986).

The intrinsic difficulty to describe convincingly and with adequate detail something that is missing can be handled in two ways: by describing its defining characteristics and by giving examples. Such a combined approach was attempted herein. The defining characteristics are outlined with motivation from three questions, which are stated and answered in Section 2. Then, an example application is described in Section 3 for the thematic field Geotechnical Engineering (and more specifically for Soil Mechanics, its theory base), which is a branch of Civil Engineering. The paper is written for readers from the field of Education, who may want to only skim Section 3.2, and for instructors of Geotechnical Engineering, who may be interested mostly in Section 3.

2 Identifying and presenting a "big idea" with help from three questions

The logic for developing the educational material follows from the answers to three key questions. Sections 2.1 and 2.2 discuss two questions that provide entry points to the core of thematic fields, while Section 2.3 explores, with the help of the third question, ways to make this core widely accessible.

2.1 What is worth being taught to everyone?

The suggested answer is "the big ideas of the disciplines". The instructional framework Understanding by Design developed by Wiggins and McTighe (2005) provides the connection between the missing knowledge and teaching. Wiggins and McTighe (2005) recommend that instructors plan courses by organizing units of instruction around the "big ideas" the course aims to develop. According to them, the term "big idea" represents "a concept, theme or issue that gives meaning to discrete facts and skills". Big ideas as presented herein are not powerful ideas thanks to their poignancy or relevance for humans (e.g. Papert, 2000), nor big themes cutting across the material world, e.g. structure of matter (Stevens et al., 2009). They are not headings of textbook chapters either. Big ideas are the major threads that run horizontally through chapters of single-discipline textbooks. They are closer to the organizing principles used by experts in arranging domain knowledge. Or, again in the words of Wiggins and McTighe (2005), "they are the hard won results of inquiry, ways of thinking and perceiving that are the province of the expert".

Identifying the big ideas worth being taught to everyone shares characteristics to Kline's (1995) recommendation to identify materials in the disciplines that every undergraduate should learn. Unlike Kline (1995) though, who recommends the formation of a committee of senior faculty to identify such materials, herein it is recommended that dedicated experts within the disciplines propose the big ideas of their own discipline. Lack of consensus is not prohibitive and will enliven the discussion. In any case, within Soil Mechanics, "effective stress" is indisputably a big idea (further discussed in Section 3.2).

2.2 How to motivate the study of a big idea?

The suggested answer is "with an essential question, phrased in everyday language". The answer follows again the guidance of Wiggins and McTighe (2005), according to whom essential questions "point to and highlight the big ideas" and "push us to the heart of things – the essence". Essential questions offer privileged access to big ideas. Essential questions and big ideas have a chicken-and-egg relationship, but for practical purposes it does not matter which one comes first. Questions are always more engaging for learners. Essential questions, whether reconstituted or spontaneous, have the additional advantage that can be phrased without technical jargon. For the big idea "effective stress", the essential question: “what happens when soil compresses” was deemed to provide a suitable entry point for further inquiry.

2.3 How to dress a big idea?

This question asks how to do justice to the big idea and its answer has two parts, a technical and a methodological. The answer to the technical part depends on the particular characteristics of the thematic field and the specific big idea. The choice made herein for the big idea of effective stress is to highlight the central role of water by considering, in the same frame, the problems of (a) loading soil by a building and (b) pumping groundwater (see Section 3.2). The methodological part is domain-general. Notwithstanding the fact that the main audience for the educational material developed is the undergraduate students of the thematic field, the suggested answer for the question posed is “with a lesson accessible to *everyone*”, where “everyone” herein also includes high school students and adults enjoying learning on the internet. In Section 3.4 it will be argued that the apparent limitations imposed by a wide audience offers opportunities to focus on the essentials, thereby facilitating conceptual understanding. Accessibility is also dually conceived, in the cognitive sense, ensured by widening the target audience, and in the literal sense, which led to choosing the production of an open online video-lesson.

For the author, the biggest opportunity offered by online material is the transformation of the near-private practice of teaching, which involves only instructors and their students, to a public practice, open to review. This opportunity paves the way for teaching to acquire the characteristics that have made research so successful and, hence, affording greater recognition and reward for teaching, as envisioned by Shulman (1993) in his evocatively titled commentary “putting an end to pedagogical solitude”. To make teaching more like research, Shulman (1993) claimed that the academy should “change the status of teaching from private to community property”, giving it thus the value we bestow to research. Shulman stresses that this can happen only from within the disciplines (this notion is echoed in Section 1 herein) and offers two more strategies to elevate the value of teaching: (i) “making teaching visible through artifacts that capture its richness and complexity” and (ii) changing the academy’s mindset to deem teaching valuable so as to assume the responsibility of judging its value. Producing such artifacts is a tall order, which, though, inspires the instructor to strive for quality material (see also Sections 3.3 and 3.5). The element of Shulman’s vision that is deemed herein to be most promising is the academy assuming the responsibility to judge the value of teaching artifacts. This element provided the idea of peer review as an integral part of developing the video-lesson. The different scope of review by peers and evaluation by students should be stressed, considering the research evidence showing that students do not judge accurately what helps them learn (Yadav, 2019).

3 The online educational material developed for the big idea of Soil Mechanics

This part of the paper provides background on some of the main decisions involved when producing online material (Section 3.1), describes the video-lesson produced (Section 3.2), the main comments of the reviewers and the resulting modifications (Section 3.3), discusses envisioned learning environments (Section 3.4) and closes with a summary of good practices considered for the production of education material (Section 3.5).

3.1 Precedents and resources

Many professors aim to emulate examples of good teaching they experienced during their own time as students. But, what would these same professors say is good teaching on the internet? Massive open online courses (MOOCs) offer examples of quality teaching judged by some objective measures. Popularity of MOOCs is one such objective measure, notwithstanding that it is highly affected by the popularity of the MOOC topic. On the interface between education and personal development, the course “Learning how to learn” (Oakley & Sejnowski, 2019) is a star-MOOC with enrolment higher than 1.8 million and subtitles in 22 languages. It is a highly engaging, short MOOC (total playing time: 3 hours, total recommended study time: 12 hours, spread over 4 weeks), with high-quality graphics. It was created by two researchers in the intersection of neuroscience, cognition and instruction. Oakley and Sejnowski (2019) apply their cognition-instruction expertise on the teaching of the topic of their own expertise (this is a rare occasion, as discussed in Section 1: most education researchers address instruction on topics other than their own, i.e. education, such as physics or mathematics).

With MOOCs, instructors have the opportunity to “attend” the classes of other teachers and, as teachers themselves now, to identify their own role-models for a teaching style they want to emulate. Having attended and completed more than ten MOOCs (and quit attending about twice as many), the author of this paper found two rich MOOCs worth emulating, especially regarding their carefully thought out structure: “Writing in the Sciences” (Sainani, 2020) and “Plato” (Kalfas, 2019). These two courses reaffirmed the author’s commitment to make visible the logical structure of material presented, which often requires a detailed storyline of a presentation before creating its slides. This storyline is the plot of the video-lesson in Section 3.2.

Searching for good examples becomes more difficult when leaving the circumscribed space of MOOCs to venture on the internet (Shoufan, 2019). When sharing with colleagues plans about developing online education material for a wider-than-university-student audience, the biggest discouragement is the response “oh, there is so much on the internet”. Further asking for recommendations for quality educational material produces websites (e.g. CrashCourse on YouTube) with collections of videos that cover a large variety of topics, including civil engineering topics (e.g. fluid flow), but very rarely recommendations on specific good videos. The author’s hesitation about such videos is that they do not provide information on the envisioned audience nor on the goals of the video. In addition, the narration is often very fast, so presumably the implicit goal is transfer of memorable info-bytes (e.g. short science facts) rather than exploration of concepts. Finally, many of these videos have graphics that are beyond the reach of a typical college instructor, so in this respect their viewing can be intimidating.

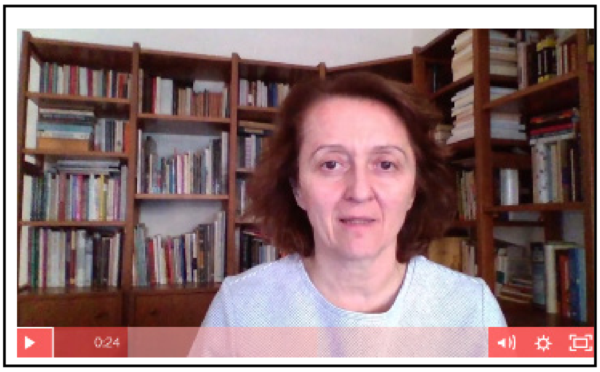
Other resources available to the educator include guides produced by university centers providing support to instructors interested in producing online materials. Some of this material is a combination of general guidelines and introductions to university facilities and procedures, e.g. for the Technical University of Delft (Mebus et al., 2013), while others are more widely useful, e.g. the description of types of educational video (i.e. videolecture, screencast, pencast, microlecture, event recording) by the University of Twente (2018).

Finally, guidance from the theory of multimedia learning is provided by Mayer (2014), who considers three main instructional goals, namely: 1) managing essential processing (help the learner select relevant information and organize it), 2) fostering generative processing (motivate and guide the learner to integrate presented material with prior knowledge) and 3) reducing extraneous processing (relieve the learner from cognitive overload). Table A1 in the Appendix shows the correspondence between these three goals and the basic principles of multimedia learning that support them.

3.2 Video-lesson description and plot

The video-lesson consists of shorter parts, as recommended for online materials (Choe, 2017), and has a total duration of a little less than 1 hour. A 3-minute introduction presents the logic and the contents of the lesson. A separate introduction is also an opportunity for the viewers to meet the instructor “face-to-face”. The remaining videos are videotaped PowerPoint presentations (screencasts): three semi-autonomous parts lasting 13 minutes (the first two) and 21 minutes (the third), and a 4-minute summary. Apart from the videos, viewers have available the PowerPoint slides and the full script of the presentations, slide-by-slide, with some additional explanatory annotations for some slides (see also Section 3.3). The accompanying slides and script facilitate revisions as well as peer review: after watching the video once, it saves time to revisit specific slides in the printed material compared with having to play again the video. The video-lesson has been recorded in Greek and in English and it is available through the website of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) (Pantazidou, 2020a;b).

The introduction asserts that even a thematic field not featured in the media, like Soil Mechanics, has one (at least) topic worth teaching to *everyone*: “what happens when soil compresses” (Figure 1). The plot of the video-lesson complements the “what” of the essential question with the respective “why” (happens what happens) and unfolds in three parts. The plot is summarized below at the simplified level of the videos (i.e. with the minimum of technical terms and the absolutely necessary explanations).



--excerpt from introduction script --

"Say that someone asks: Does Soil Mechanics have something worth teaching to everyone? I would answer: Yes, it does! What happens when soil compresses.

I develop my answer in three parts, three short lessons, and a summary. I prepared the lesson for high-school students, for our students and for all of you who like to understand."

Figure 1. Introducing the essential question "what happens when soil compresses"

Part 1 considers as an example of compression the settlement of a building and introduces the main "actors" of soil compression (soil grains, soil pores, soil skeleton), as well as the quantities necessary for quantifying settlement (weight, load, pressure, stress) with slides such as those shown in Figure 2. With the aid of a cartoon with magnified grains of dry sand, a first descriptive answer to the motivating question is given as: "when soil compresses, it is the soil skeleton, i.e. the assemblage of soil grains, that compresses: soil grains come closer together, while the volume of the pores decreases". The importance of the location of the ground water elevation is stressed (while the term "water table" is avoided, so as not to burden the viewers with jargon), as well as that below this level the soil is saturated, i.e. the space of the pores is occupied only by water. The explanation of the term "saturated" is repeated a few times throughout the lesson, because the word has some additional, potentially confusing meanings. The remaining video-lesson deals only with saturated soils, which settle while at the same time the excess water, which does not fit in the tighter configuration of grains, escapes. In a sand, this excess water will leave quickly. But in a clay it will leave slowly, because water flows very slowly through the very small pores of clayey soils. That's why, in clayey soils, if the settlement of a building is large, we should wait until it is completed before we connect the building to the water and the sewage pipes or, if we cannot wait, we should speed up its completion.

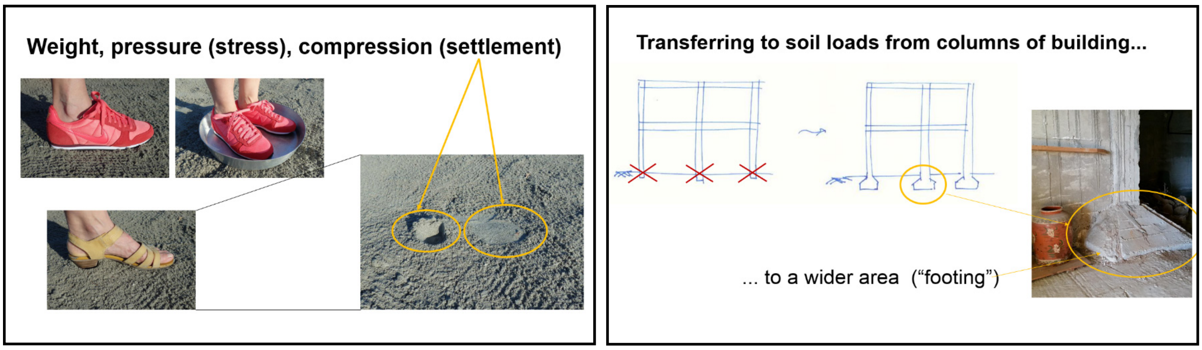


Figure 2. Slides from Part 1: relationship between weight, area of foot support or building foundation (shoe, pan, sandal with heel, footing of a building) and compression

Part 2 deals with pumping water, because pumping also causes settlements. This second part aims to pique the curiosity of the viewers as to why two seemingly unrelated civil engineering projects (construction of a building and pumping groundwater – see Figure 3) have the same result (compression) and to motivate them to watch Part 3, which gives the answer in terms of effective stress, the big idea of Soil Mechanics. Part 2 presents two emblematic cases of settlement due to pumping. Venice, where pumping resulted in settlement of 13 cm: although not a large settlement, it creates problems for Venice where the ground level is very close to the sea level (Carbognin et al., 2005). And Mexico City, where settlements have been as large as 7 to 10 meters (Auvinet, 2016). The comparison of the two cases shows that soils described as loose (sands) or soft (clays, e.g. the Mexico City clay) have large volume of pores (again, Soil Mechanics terms such as porosity and void ratio are avoided), that's why they can compress a lot.

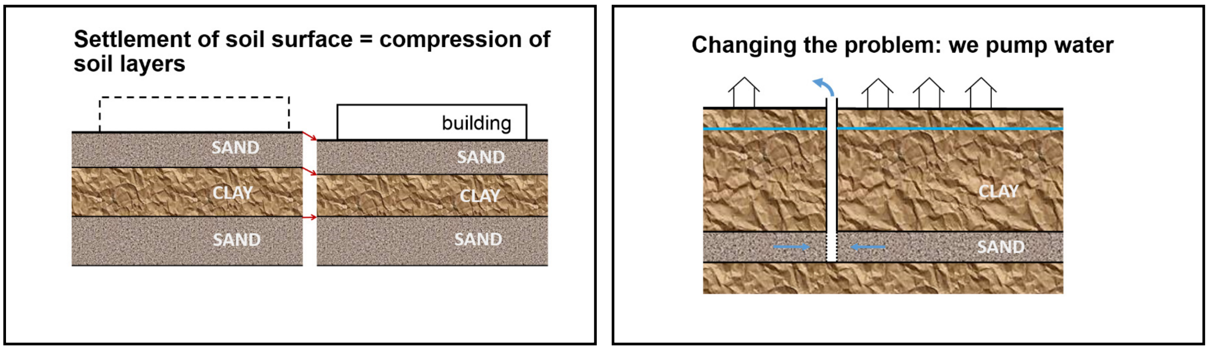


Figure 3. Two civil engineering projects causing settlement: construction of a building (slide from Part 1) and pumping water (slide from Part 2)

The goal of Part 3 is to explain how can Soil Mechanics predict quantitatively the settlement of soil, having defined the foundational concept –the big idea– of effective stress, and to also give some theoretical and historical background (Figure 4). Part 3 asks "how is it possible that water pumping causes settlement, since it does not apply any additional load on the soil, like does the weight of a building?" To answer this question, it is necessary to distinguish between two stresses: the total stress (σ), which is due to the loads applied on soil, and the effective stress (σ'), which expresses what is felt by the soil skeleton. Effective stress (σ') is equal to total stress (σ) minus the pressure of the water (u) in the soil pores, that is, $\sigma' = \sigma - u$. To understand the role of the water pressure in the expression (i.e. its negative sign), it helps to think of buoyancy, which makes us feel our body lighter in the water. That's why it is important to know the location of the water level, because it is related to the water pressure and, hence, to effective stress. Since effective stress (σ') is equal to σ-u, it increases (and, hence, soil compresses) when the total stress (σ) increases, or when the pressure of the pore water (u) *decreases*. This happens when we pump: the water pressure drops, the stress felt by the soil skeleton increases and, hence, soil compresses. For the quantitative prediction of settlement, we need to (1) calculate the effective stress increase and (2) perform experiments in the laboratory to connect the increase of effective stress to the compression of soil samples we have obtained from the area under study.

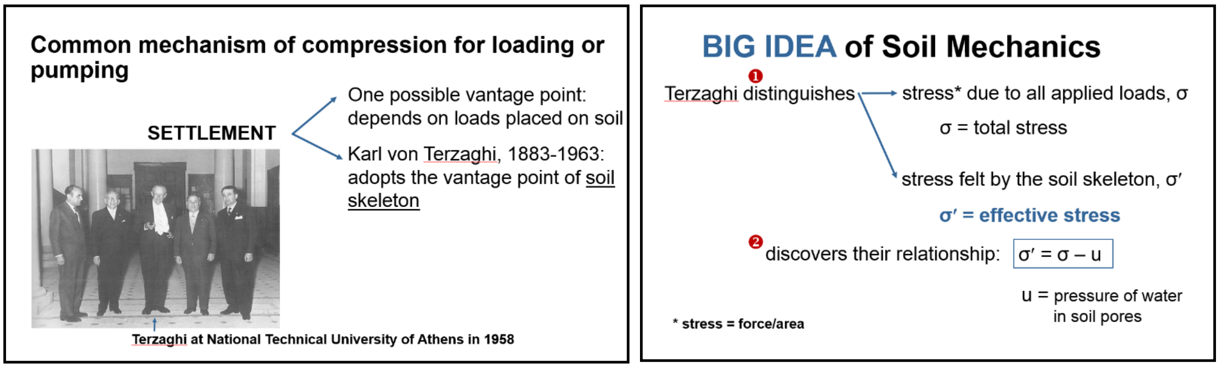
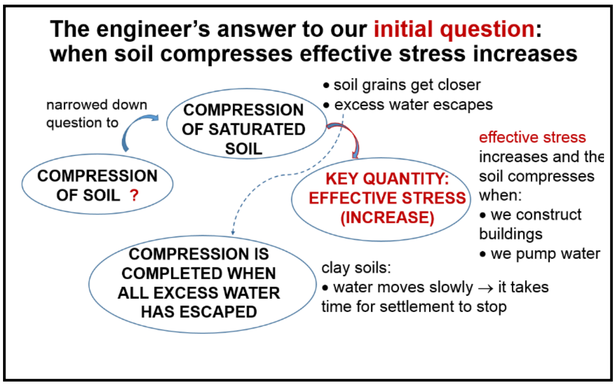


Figure 4. Slides from Part 3 guiding the viewer to follow the conception of the big idea "effective stress" by the founder of Soil Mechanics, Karl Terzaghi

Part 3 concludes with another example of settlement of ground at low elevation, in fact below sea level, in Holland. In Holland too, pumping of water resulted in settlement. However, the settlement in Holland is primarily a result of a chemical phenomenon, the oxidation of organic soil, which shrinks and compresses when it comes into contact with the oxygen in the air entering the pores, due to the drop of groundwater *level*. So, it would be wrong to conclude that since pumping caused settlement in Holland as well, settlement was also due to a mechanical phenomenon, like the increase of effective stress due to the drop of the *pressure* of groundwater.

Finally, the 4-minute summary gathers (i) in one slide the answer to the question "what happens when soil compresses" (Figure 5a) and uses the study of soil compression (ii) in a second slide as an example of prediction of how engineering projects may impact natural processes, and (iii) in a third and final slide as an opportunity to generalize the way the applied engineering sciences work (Figure 5b).



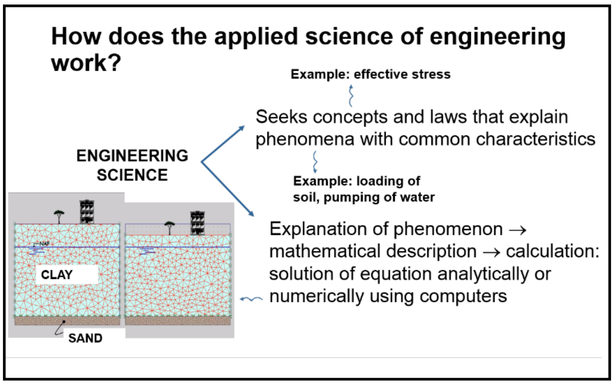


Figure 5. Slides from the Summary: (a) synopsis of answer to essential question (slide is presented in animation mode, starting from "COMPRESSION OF SOIL ?" and proceeding clock-wise) and (b) generalizing the methodology followed to answer the question (figure from Auvinet, 2016)

3.3 Review comments & modifications

The videos were first recorded in Greek and then comments were sought from four reviewers. Their comments resulted in modifications of the presentation slides and the script, which were then translated in English and the videos were recorded again (in English only). The reviewers were three professors in Departments of Civil Engineering in Greece, two with a specialization in Geotechnical Engineering and one with a specialization in Environmental Engineering and prior experience with attending and completing MOOCs. Comments were also offered by a representative of the wider public, who was sought in the personal circle of the author, with criteria to have (a) prior experience with attending and completing MOOCs and (b) non-engineering background (the reviewer had a background in the Humanities). The types of comments provided by the four reviewers grouped their input into two categories which were different than those originally anticipated by the author (i.e. the three engineering professors and the representative of the wider public): reviewers with or without geotechnical engineering background, regardless of university affiliation or engineering background.

The two geotechnical engineering professors asked mainly for clarifications so as to avoid possible misunderstandings. Such examples included a suggestion that when saying "in general, sands compress less than clays", we should stress that this is true for the same applied load. Or that it may be confusing for the students to hear about soil underneath a building and see a 2-dimensional (2D) sketch. They also asked for additional information on topics outside the geotechnical engineering domain (e.g. why does the sea rise in the Adriatic region close to Venice). These comments led mainly to adding annotations to the script, in the respective slides. In one instance, where the first 2D cross-section appears (Part 1, Slide 5), a figure was added to the script, explaining the correspondence between 2D and 3D, and a note was added to the narrative, inviting the viewers to check the script for additional explanations. The two geotechnical reviewers were also more demanding on quality issues (clearer pictures, animations instead of still pictures): these comments were taken into account to the technical degree possible, e.g. a simple animation was added in Slide 8, Part 1. The initial plan for the preparation of graphics used in the slides was that the author would make first sketches from which a professional would produce the final versions: such professional help could not be procured in Greece (despite contacts with graphic design schools, publishers of engineering textbooks and with faculty members at education departments), so the author ended up producing everything herself.

One of the two geotechnical reviewers found rather tiring the discussion of potential ideas for exploring the mechanism of settlement discussed in Part 3, before arriving at effective stress. In response to this comment, the English version of Part 3 is shorter by two slides, since indeed this exploratory part could be made shorter while preserving some references to how engineering proceeds with solving theoretical problems. The same reviewer did not see value in the historical reference to the founder of Soil Mechanics, Karl Terzaghi, and also thought that the discussion of the settlement in Holland is off topic. These two comments did not result in changes, each for a different reason. The historical reference to Terzaghi remained because it is more vivid (apart from being true) to explain that one particular person made the key realization that permitted the application of Mechanics to soils and, thus, created Soil Mechanics. The reference to the settlement due to pumping in Holland remained because it serves two purposes. First, it contributes to the broader discussion on engineering at the beginning of Part 3 (Slide 5: engineers often extend the use of existing tools for new problems with suitable modifications) and then in the summary (Slide 3: discussion of unanticipated impacts of engineering projects). Second, it alerts the viewer against always associating the settlement resulting by pumping to the mechanical phenomenon caused by the decrease of pore water pressure, which was the author's first impression when she started reading on the internet about Holland. In fact, after reading an article about the settlement in Mexico City in the New York Times (Kimmelman, 2017) and recent publications discussing cracks appearing on the soil surface in the Mexico City area (Auvinet et al., 2017), the author finds it more probable that in Mexico City as well settlements nowadays are due to two mechanisms, soil shrinkage and increase of effective stress. Unfortunately, she was unable to have the authors of the relevant publications to comment, but she is hopeful that when the video-lesson and this paper are published, comments are bound to materialize. As mentioned in Section 3.3, instructors who widen the scope of a lesson and make connections to real-life cases end up spending more time because (i) they venture outside their zone of expertise (e.g. having to look up eustacy) and (ii) real life seldom conforms 100% to principles presented in theory. This orders-of-magnitude higher time involvement can be compensated by involving the geotechnics community (Shulman, 1993).

On the contrary, the two reviewers without geotechnical engineering background focused on difficult key points and commented on their efforts to address these difficulties of understanding. Sample comments included misunderstandings ("how come we calculate stresses and pressures only at the lower point of soil layer but then we talk about the settlement of the entire layer?"), uncertainties created by the video ("we only talk about saturated clay, so are we to conclude that dry clay does not settle?") and attempts to understand effective stress as a physical quantity (which is not a productive idea, it is better to think of effective stress as a concept, a useful tool to describe the behavior of soil). The buoyancy analogy, included in the English version, is meant to help the viewers who might go beyond following the material presented and attempt to create their own understanding of the big idea of effective stress.

Comments made by non-expert reviewers are invaluable for the instructor, because they are close to comments students would have made, if they had the metacognitive abilities of the reviewers, who would be classified as highly experienced learners. Domain experts often find it difficult to anticipate learning difficulties of novices, a characteristic known in the education literature as "the expert's blind spot" (Ambrose et al., 2010). Since the video-lesson in Greek was not recorded again, the comments of the non-geotechnical reviewers were addressed in annotations to the script. For the video-lesson in English, their comments helped with (i) modifying the narrative itself (i.e. the script) to provide additional explanations (ii) adding small clarifications to the slides (e.g. notifying the viewers that the scripts include annotations as already mentioned), as well as (iii) providing additional explanations as annotations to the slides. Annotations were deemed to be very useful and convenient because they allow some side notes without interrupting the presentation flow and increasing the duration of the video.

3.4 Intended and suggested audiences and learning environments

As already mentioned, the primary audience of the video is university students in civil engineering departments; targeting such an audience ensures the technical fidelity of content (yes, simplifications are made, but not to the point of altering the essence). The educational material will be used by the author in a Soil Mechanics course at the National Technical University of Athens. Before recording the video, selected slides from Part 2 were included in the lecture on consolidation, when students already know of the importance of effective stress: as mentioned, the point was to unite, in a single frame, soil loading and pumping. In class, the description of the slightly compressible clayey silt in Venice and the highly compressible Mexico City clay is accompanied with the respective values of their compression indices, C_c=0.1-0.29 in Venice, and C_c=3-8 in Mexico City.

With the video available now, students will be asked to watch it on their own, after the lecture on determining 1D settlement and before the lecture on the evolution with time of settlement due to consolidation. Then, the discussion in class will focus on what more can civil engineering students say about the material presented in the video. This discussion can be motivated with the aid of some questions at a level suitable for civil engineering students, e.g. if we stop pumping, will the soil surface return to its pre-pumping levels?

Civil engineering students have much to gain by viewing and discussing a simplified version of material presented in class. For the specific topic under study, the video-lesson offers to civil engineering students an opportunity to contrast sand-clays and dense/hard-loose/soft soils. More generally, simplified versions of adequate fidelity afford opportunities for students to (1) place emphasis on concepts and think qualitatively of the implications of the quantities they use in calculations (e.g. the void ratio) and (2) reactivate their own knowledge through the invitation to enrich the simpler version, thus getting a glimpse of expertise. Perhaps it would be a good idea for the university student to watch the video-lesson with a high school student and have the responsibility to answer any questions.

Another option would be to use the video-lesson in an introductory lecture for Soil Mechanics, for a mixed audience consisting of civil engineering students and some invited high school students contemplating studies in Civil Engineering. The instructor could make the presentation using the actual slides or can show the video in parts, and having a discussion after each part. The goal for the high school students is to see their future self, and for the civil engineering students to see the subject of Soil Mechanics in a context broader than typically allowed in weekly lectures. At the semester's completion, civil engineering students will be asked to watch the video again and, with the semester's knowledge, answer more advanced questions.

One additional learning environment, at the high school level, concerns the broadening of knowledge useful for career guidance. A future extension of this work will add video-lessons for big ideas from other civil engineering thematic fields (e.g. Structural Engineering, Transportation Engineering, Hydraulic Engineering). These video-lessons will help high school students interested in civil engineering studies become familiar not only with projects involving civil engineers, but also with the types of problems they will deal with as students in a civil engineering department.

Finally, the video-lesson may be of interest to those who find attractive using their free time to learn university-level material. In this more unstructured environment, the video-lesson offers the viewers (1) mental exercise for explanations requiring several steps (layered understanding requires more time than info-bytes) and (2) some appreciation of impacts of engineering projects and the work method of engineering.

3.5 Good practices followed (or not)

As with all educational material developed by teachers for the benefit of their students, it is difficult to tell whether the video-lesson helps students learn better. As mentioned, self-assessments of students have little value with respect to what helps them learn (Yadav, 2019), so it takes a research project to answer convincingly the question "did they learn better". In the absence of results from such a project, this section lists some of the good practices followed (or not) in developing the video-lesson. As mentioned, the video-lesson was designed in shorter, semi-autonomous parts conforming to the guideline to keep videos short to keep the viewers engaged (Choe, 2017). This guideline could not be followed in Part 3, which was broken down into parts A and B, so as to at least create a break point. The guideline to keep slides sparse (Grob, 2015) was not followed in the slides where the viewers need to follow separate steps of an explanation. But even in these slides, animation is used to present to viewers the material is smaller chunks and, thus, guide their attention (Grob, 2015). The guideline for inserting quiz questions in the presentations, which is the norm in MOOCs, was not followed due to limited functionalities of the free version of the recording software used (Active Presenter). Finally, from a content point of view, the video-lesson includes elements viewers can easily connect with, such as everyday experiences (from sand beaches) and real case studies. In terms of Mayer's (2014) multimedia design principles (see Table A1 in Appendix), most of the principles were followed to a varying degree, with the exception of: the redundacy principle (at several slides, the same information was both printed and narrated – this was done so that the student can pause the presentation and see the text) and the voice principle (the video-lesson in English is narrated by the foreign-accented voice of the author).

4 Concluding remarks

This paper aimed to present a pilot for the production of future stand-alone video-lessons. To this end, it devoted equal space to the description of the developed material in geotechnical engineering and the methodological underpinnings of the undertaking. The hope is that some instructors will find some idea(s) useful for their teaching, while some others will be inspired to produce something better. In terms of methodology, the paper (i) argued that addressing an audience larger than only university students helps the instructors focus on the more fundamental aspects of their discipline and (ii) placed emphasis on the public character of online teaching, which makes possible peer teaching reviews. Beyond geotechnical engineering, the ultimate goal is that domain experts will be challenged to identify the big ideas and essential questions of their own domain and write about them.

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Appendix

Table A1. Basic principles for designing multimedia environments and respective instructional goals (from Mayer, 2014)

Instructional Goal	Name of Principle	Description of Principle: People learn better …
Manage Essential Processing	Multimedia	… from words and pictures than from pictures alone
	Modality	…from graphics and narration than from graphics and printed text
	Segmenting	…when a multimedia message is presented in learner-paced segments rather than as a continuous unit
	Pre-training	…when they know the names and characteristics of the main concepts
Foster Generative Processing (motivation - related)	Personalization	…when the words are in a conversational style rather than formal style
	Voice	…when the words are spoken in a standard-accented human voice rather than a machine voice or foreign-accented human voice
	Embodiment	…when on-screen agents display human-like gestures[1]
Reduce Extraneous Processing	Spatial & Temporal Contiguity	…when words and pictures are integrated in space and time
	Redundancy	…when the same information in not presented in more than one format
	Signaling	…when cues are added that highlight the key information and its organization
	Coherence	…when extraneous material is excluded

[1]…but not necessarily when the speaker's image is on the screen

Author's bio

Marina Pantazidou, National Technical University of Athens, Greece

Marina Pantazidou is an associate professor at the National Technical University of Athens (NTUA). Before joining NTUA in 2001, she worked in geoenvironmental consulting in the US (1991-1993) and was an assistant professor at Carnegie Mellon University (1994-2000). In 2000-2001, she was a visiting scholar at the Graduate School of Education at UC Berkeley. Her research interests include (1) environmental geotechnics and (2) engineering education. She has authored 90 journal and conference papers, about a third of which on education topics, and has edited two special journal issues on geotechnical engineering education. She is a member of the American Society of Engineering Education, the Hellenic Society of Soil Mechanics and Geotechnical Engineering (Secretary General, 2012-2015, and Board Member, 2015-present), and the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). She has been a core member of ISSMGE's Technical Committee for Geo-engineering Education (TC 306) since 2010, Vice Chair for the 2013-2017 term, and Chair for the 2017-2021 term.

Links to Research on Learning and on Engineering Education

The Effect of Attending or Missing Lectures on Soil Mechanics Examination Performance

G.C. Fanourakis

University of Johannesburg, South Africa
georgef@uj.ac.za

ABSTRACT: The effect of class attendance or absence on the performance of students is often debated. This investigation assessed the effect of the extent of lecture attendance or absence on the performance of 63 Soil Mechanics students of the Civil Engineering Technology Programme, at the University of Johannesburg, South Africa. The results indicated that a correlation exists between the extent of absence and attainment. A total of 6 of the 10 students who did not qualify to sit the examination attended a maximum of 1 lecture. Of the 53 students who sat the examination, it was evident that the pass rate generally improved with increased lecture attendance. More specifically, no students who attended less than 30 % of the lecture sessions passed the examination. In addition, 87 % of students who attended up to approximately 55 % of the lectures failed. A significant correlation (P = 1.3 % and r = 0.779) was established between the number of students that failed and the number of lectures missed. Finally, a highly significant correlation (P = 0.006 % and r = 0.956) was established between the chances of passing an examination and the number of lecture sessions attended.

Keywords: Soil Mechanics, Attendance, Attainment

1 Introduction

Soil Mechanics 2A is a compulsory course of the National Diploma: Engineering: Civil in South Africa. Instruction in this course is offered primarily by means of lectures (with associated presentations that are made available to the students), course notes (which include graded tutorials at the end of each chapter) and laboratory practical sessions. In addition, students have access to the Blackboard System which enables them to access information about the course, course notes, other additional resources (such as relevant journal papers) and announcements. Videos of the lectures have not been recorded.

The course syllabus comprises an introduction to soil mechanics, problem soils, soil formation, phase relationships, classification, site investigation, compaction and sub-surface water. The successful completion of this module is expected to impart the fundamentals of soil mechanics, including theory, methods of analysis and laboratory tests to enable the solving of soil mechanics problems.

The course has always been assessed by two closed book tests, a laboratory report and an examination. A semester mark was compiled on the basis of weighting Test 1, Test 2 and the laboratory report in ratios of 40 %, 40 % and 20 %, respectively. Students with a semester mark of 40 % or more are permitted to sit the examination (on the entire syllabus). The final mark for the subject is calculated by combining the semester and examination marks in the ratio of 40:60. A final mark of 50 % is considered as a pass.

The effect of lecture attendance or absence on the performance of students is often debated. There are a number of reasons why students miss lectures including financial, as some students are faced with a decision whether to use the transport money for food instead. In addition, some students commence attending lectures relatively late, after a few lectures have already taken place, as they do not have the funds to register at the beginning of the semester.

Another common reason for absenteeism is studying for a test scheduled on the following day.

The benefits of attending lectures include exposure to worked examples, interaction with the lecturer and other students as well as continuous progress in terms of covering the syllabus (as opposed to procrastination of learning until immediately prior to assessment opportunities).

The University of Johannesburg has a regulation that at least 80 % of lectures and other relevant components of a course (e.g. laboratory practical sessions) have to be attended.

The author has unofficially observed that the students who perform very well in a course generally attend lectures. Efforts have always made to increase pass rates. However, these may be futile if students are not attending lectures. Hence, it was decided to assess the effect on lecture attendance (or absence) on the performance in the examination, by considering each student. Although there may be a relationship between the mark attained in the examination and the final mark attained in the subject by students, the final mark was not considered in this investigation, as it is based on tests as well as a group laboratory project. Incidentally, the final mark pass rates are higher than the examination pass rates due to the consideration of test marks (each on selected sections) and the laboratory report. The examination marks are often generally lower than test marks, as the examination is on the entire syllabus.

This paper considered the following hypothesis:

The fewer lectures students miss in a course, the better their chance of passing the examination.

2 Literature review

Kelly (2012) investigated lecture attendance rates and related factors, at University College Dublin, (Ireland). This study was based on two probability-based surveys, based on a questionnaire which considered factors that influence attendance that are in control of the university (such as the timetable) as well as those that are dependent on the students (such as part-time work).

Using a different approach, Massingham & Herrington (2006), investigated reasons for absenteeism in the Faculty of Commerce at the University of Wollongong (Australia). They established a relationship between attendance, participation and performance.

Many researchers, in various countries, have conducted research into the relationship between lecture attendance and results achieved (attainment), including Romer (1993), Devadoss & Foltz (1996), Colby (2004), Burd & Hodgson (2006), Newman-Ford et al., (2008), Meulenbroek & van den Bogaard (2013) and Kwak et al. (2019).

Romer (1993) investigated the effect of lecture attendance in a macroeconomic course at Berkeley (USA). He established a positive correlation.

Devadoss & Foltz (1996) studied the effect on lecture attendance on the performance of 12 agricultural economics courses at the University of Idaho (USA). The performance considered exams, quizzes, projects and assignments. A significant relationship was established.

Colby (2004) investigated this relationship in a computer science course at the University of Central England (UK). His research led to the establishment of the following two rules of thumb.

- The 70 % rule: a student who attends more than 70 % of teaching sessions has a chance of failing lower that 0.67, and a chance of getting a first or upper second higher than 0.2.
- The 80 % rule: a student who attends more than 80 % of teaching sessions has a chance of failing lower than 0.5, and a chance of getting a first or upper second higher than 0.33.

Burd & Hodgson (2006) investigated the effect of lecture attendance on the examination marks of 5 compulsory courses (Computer Systems II, Software Applications, Theoretical Computing, Programming and Reasoning and Software Engineering) in the computer science department, over a five-year period, at the University of Durham (UK). They established a significant correlation (0.05 confidence level). Hence, they concluded that this relationship was unlikely to be due to chance.

In their investigation, Massingham & Herrington (2006) also concluded that relatively increased attendance resulted in relatively better performance.

Newman-Ford et al., (2008) conducted research into the effect of attendance on attainment, in coursework and examinations, of 22 psychology and criminology courses, at the University of Glamorgan (UK). They established a significant correlation (P=0.0001). They also concluded that these results were unlikely to be attributed to chance. Furthermore, two-thirds of students who failed attended between 10 % and 30 % of lectures and the average attendance of students who passed was 60 %.

Meulenbroek & van den Bogaard (2013) studied the effect of attendance on the marks of calculus exams, at the Delft University of Technology (Netherlands). They found that students that attend more than 75 % of classes had a higher pass rate.

Kwak et al., (2019) evaluated the effect of lecture and tutorial attendance on attainment. This study found the test scores to increase by 1.3 % per lecture attended.

Hence, considering the above results of other investigations, which all indicate a correlation between attendance (or absence) and performance, the specific objective of this paper was to verify this correlation in the case of the Soil Mechanics course being investigated. The effect of online materials (such as the lecture presentations) on performance was not assessed.

3 Methodology

The attendance of lectures of a group of 63 students, over an entire semester, in 2017, was recorded. This was done using the *Blackboard* Online System, where, immediately after every lecture session, the author (lecturer) accessed the system and a code was generated by the system. This code was, in turn, given to the students and they had five minutes to enter it on their student profile (using the Blackboard application), using a smart phone and the university's Wi-Fi network. The system then e-mailed a spreadsheet, with the details of the students who attended that lecture session, to the lecturer. This spreadsheet included student numbers, IP addresses, exact date and times, and coordinates (in the cases where location on the smart phone was enabled). Students who did not possess smart phones utilised the phones of other students.

The lectures for this course comprised a total of 11 weekly sessions. Each session comprised 3 consecutive 50 minute lectures, separated by a 5 to 10 minute break. Attendance of the first lecture, where the course (including the study guide) was discussed, was not recorded. In addition, due to an unknown reason, the attendance spreadsheet received for 1 other lecture was blank. Therefore, attendance was recorded for a total of 9 sessions.

This investigation considered all the registered students and did not make a distinction between those who were repeating the course. Interestingly, Colby (2004) found that repeat students had a higher failure rate (51 %) compared to the first-time students (23 %).

The attendance of students who did not qualify to sit the examination was considered. Furthermore, in the case of the students who gained entrance into the examination, the attendance of the lecture sessions was correlated with the examination mark.

4 Results and discussion

4.1 Examination entrance

Of the 63 students included in the investigation, 53 students obtained entrance into the examination.

Table 1 shows the number of students who attended the different number of sessions as well as the number of students who did not gain entrance to the examination. The average attendance was 4 sessions (44 %).

Table 1. Attendance of sessions and qualification for the examination

Results	Number of Sessions Attended									
	0	1	2	3	4	5	6	7	8	9
No. of Students (63)	9	7	3	4	5	11	6	13	5	0
No. of students Excluded from Exam (10)	4	2	1	1	0	1	0	1	0	-

From Table 1, it is evident that:

- None of the student attended all 9 lecture sessions.
- 60 % students that did not write the examination attended 0 or 1 lecture session.
- All students who attended 8 lectures qualified to sit the examination.

The percentage the students who did not qualify to sit the examination, in each of the number of sessions attended, is shown in Figure 1.

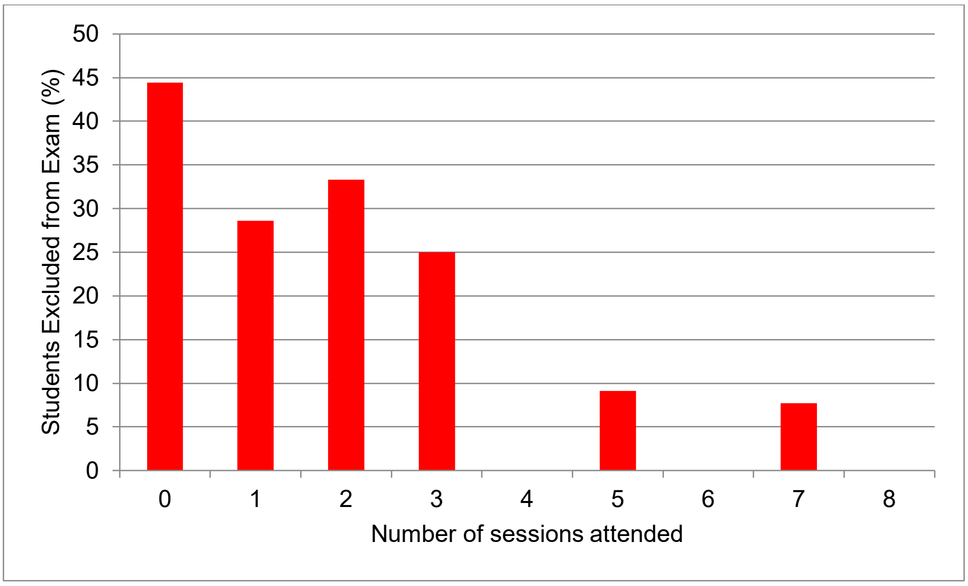

Figure 1. Percentage of students who did not qualify to sit the examination

It is evident from Figure 1 that, generally, a larger percentage of the students who attended fewer sessions did not gain examination entrance.

4.2 Examination statistics

The statistics pertaining to the 53 students who sat the examination are shown in Table 2. The performance of these students is considered below.

The average attendance was 5 sessions (56 %). The lowest, average and maximum marks for the examination were 9 %, 40 % and 88 %, respectively.

Table 2. Attendance and results of examination qualifying students

Results	Number of Sessions Attended									
	0	1	2	3	4	5	6	7	8	9
No. of Students (53)	5	5	2	3	5	10	6	12	5	-
Fail (40)	5	5	2	2	5	7	5	6	3	-
Pass (13)	0	0	0	1	0	3	1	6	2	-

It is evident from Table 2 that the overall examination pass rate was 25 %.

Comparing the data in Table 2 to Colby's (2004) 70 % and 80 % rules, students who did not attend at least 70 % (6 sessions) or 80 % (7 sessions) of sessions had an 87 % and 86 % chance of failure, respectively. This translates to an almost 1 in 10 chance of passing. This failure rate is higher than the values given by Colby (2004) of 67 % and 50 % chance of failure at attendance rates less than 70 % and 80 %, respectively. On the other hand, Burd & Hodgson (2006) obtained better pass rates than Colby (2004) in that 40% and 37 % of students who attended less than 70% and 80 % of the lectures failed. Newman-Ford (2008) also achieved reduced chances of failure compared to Colby (2004).

Table 3 shows the statistics, from Table 2, grouped according to equal sized session ranges.

Table 3. Attendance and results according to session ranges

Results	Number of Sessions Attended		
	0-2	3-5	6-8
No. of Students (53)	12	18	23
Fail (40)	12	14	14
Pass (13)	0	4	9

Figure 2 shows pass and failure rates as a percentage of the number of students in each of the ranges in Table 3.

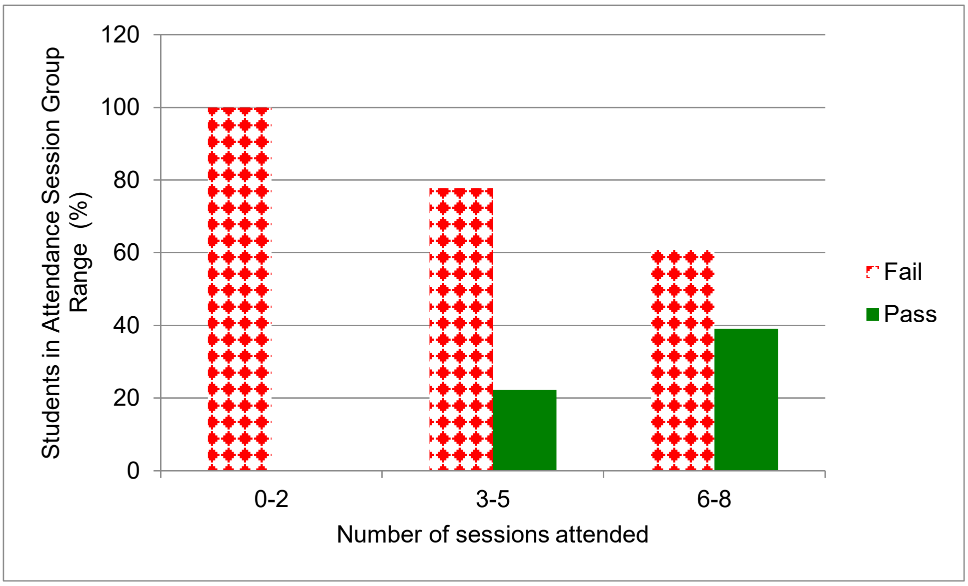

Figure 2. Success rates for different session attendance ranges

Furthermore, It is evident from Tables 2 and 3 and Figure 2, that the pass rate generally improved with increased lecture attendance. This in agreement with Romer (1993), Devadoss & Foltz (1996), Colby (2004), Burd & Hodgson (2006), Newman-Ford et al., (2008), Meulenbroek & van den Bogaard (2013) and Kwak et al. (2019).

Referring to Table 3, the following is evident:

- No students who attended less than 3 lecture sessions passed.
- 87 % of students (26 of 30) who attended 0 to 5 lecture sessions (up to approximately 55 % of lectures) failed.
- 61 % of students (14 of 23) who attended between 6 and 8 lecture sessions (approximately 70 % to 90 % of lectures) failed.

Figure 3 shows the relationship between the percentage of students that failed the examination and the number of lectures missed. This relationship is based on Table 2, for example 5 out of 5 (100 %) students missed all 9 lectures (attended none) and 3 out of 5 students (60 %) missed 1 (attended 8 lectures). This relationship yielded a correlation coefficient (r) of 0.779 and was significant with P = 1.3 %.

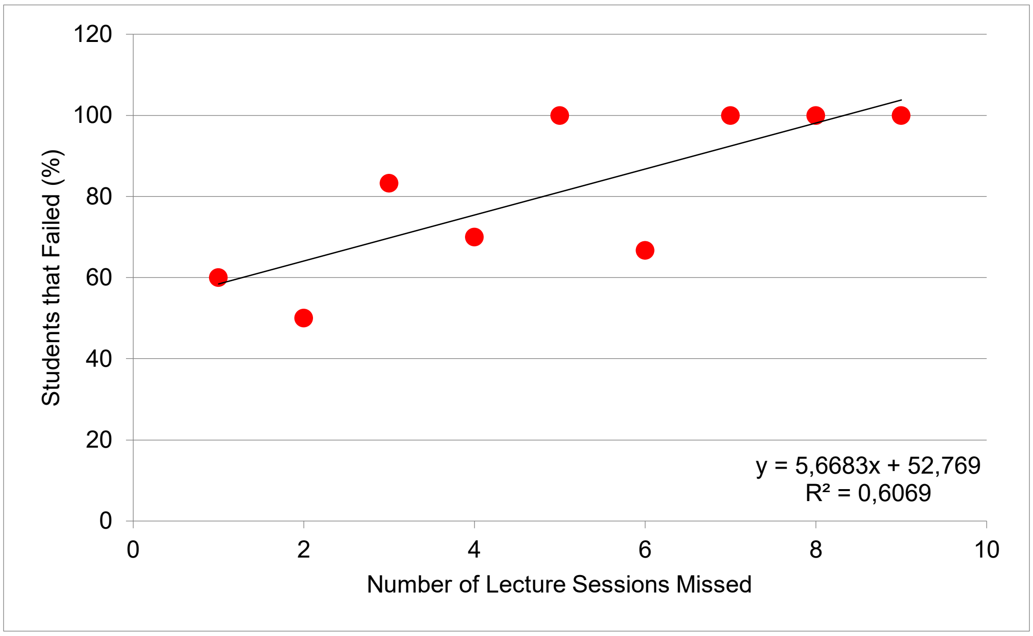

Figure 3. Success rates for different session attendances

From Figure 3, it is evident that, generally, students who missed approximately half of the lectures (5 out of 9; 55 %) failed. Furthermore, 60 % of students who missed only 1 lecture failed.

Figure 4 shows the relationship between the percentage chance of passing and the number of lecture sessions attended. This relationship yielded a correlation coefficient (r) of 0.956 and was highly significant with P = 0.006 %.

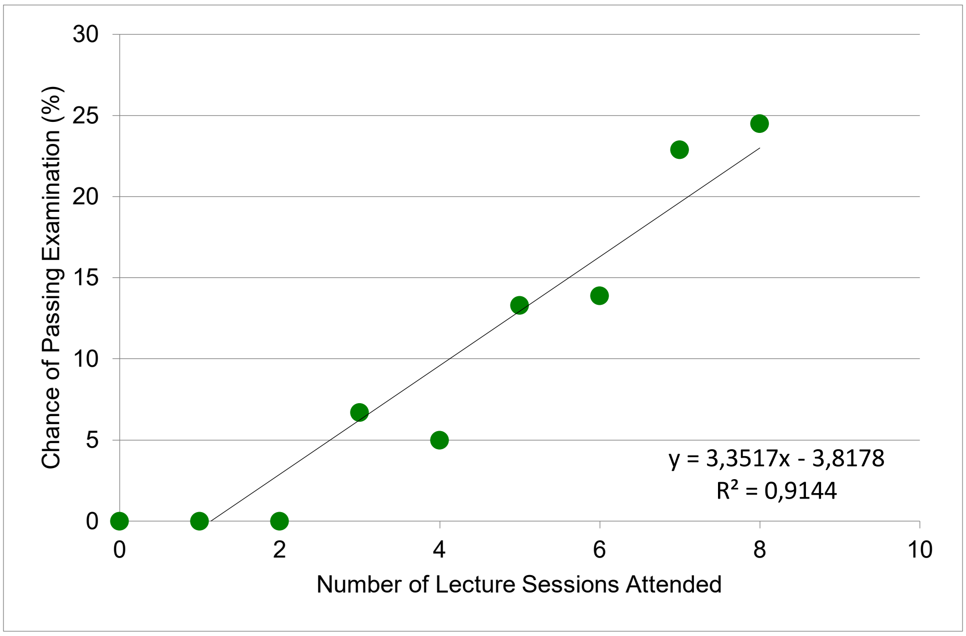

Figure 4. Percentage chance of passing versus lecture attendance

From Figure 4 and Table 2, it is evident that students who attended 33 % of lectures (3 lectures) had a 6.7 % (1/(5+5+2+3)) chance of passing, compared to students who attended 88,9 % of lectures (8 lectures) who had a 24.5 % (13/53) chance of passing, which is a 75.5 % chance of failing.

Finally, it should be borne in mind that although the results of this investigation were specifically compared with those of others, the nature of the course investigated here (Soil Mechanics) is very different from the courses investigated by other researchers (e.g. Economics, Computer Science and Criminology). Hence, differences in results may be justified. It is recommended that the correlations established be validated by additional data.

Incidentally, 30 of the 53 students (57 %) who wrote the examination passed the course (Final Mark).

5 Conclusions

The correlation between attendance of lectures and attainment in the Soil Mechanics examination was investigated.

A total of 10 of the 63 students considered did not gain entrance into the end of semester examination, based on their marks in the test and the laboratory report, during the semester. A total of 6 of these students attended a maximum of 1 of the 9 lecture sessions.

Of the 53 students who wrote the examination, it was evident that the pass rate generally improved with increased lecture attendance. More specifically, no students who attended less than 3 lecture sessions passed. In addition, 87 % of students who attended 0 to 5 lecture sessions (up to approximately 55 % of lectures) and 61 % of students who attended between 6 and 8 lecture sessions (approximately 70 % to 90 % of lectures) failed.

A significant correlation ($P = 1.3$ % and $r = 0.779$) was established between the number of students that failed and the number of lectures missed. The results indicated that 60 % of the students who missed only 1 lecture failed.

Finally, a highly significant correlation ($P = 0.006$ % and $r = 0.956$) was established between the chances of passing an examination and the number of lecture sessions attended.

As the correlations established are specific to the Soil Mechanics course investigated, they may not apply to other courses in the qualification or courses in other schools.

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Author’s bio

George C. Fanourakis, University of Johannesburg, South Africa

Professor George C. Fanourakis joined the Department of Civil Engineering Technology at the (now) University of Johannesburg (UJ) over twenty-six years ago, after leaving his employment at Jones and Wagener (Pty) Consulting Engineers. He received the degrees MSc(Eng) from the University of the Witwatersrand and a DTech(Eng) from the UJ. He is a Chartered Civil Engineer and Fellow of the Institution of Civil Engineers (UK). He is a Fellow of the South African Institution of Civil Engineering, Honorary Fellow and Past President of the Institute of Professional Engineering Technologists, Member of the Soil Science Society of Southern Africa and Member of the fib (Fédération Internationale du Béton). His professional involvement includes serving on three Geotechnical National Standards (SABS) Committees as well as Membership of Commission 9: Dissemination of Knowledge, of the fib. His primary general teaching and research interest areas are Geotechnical Engineering and Concrete Technology. In addition, Prof. Fanourakis is active in research in engineering education.

Introduction of Cooperative and Competition-Driven Learning in Geotechnical Engineering Education

E.S. Ieronymaki, M. Omidvar & D. Rabadi

Department of Civil and Environmental Engineering, Manhattan College, NY, USA
ieronymaki@manhattan.edu, momidvar01@manhattan.edu, drabadi01@manhattan.edu

ABSTRACT: Geotechnical engineering education relies heavily on traditional methods of teaching where theory is presented first, followed by applications. The current paper presents an alternative way of teaching Soil Mechanics to junior level students, incorporating cooperative learning and competition. Students worked in groups to solve in-class and homework assignments while competing with each other on completing the assignments, with bonus points accumulated for correct answers. The goal of the suggested teaching approach was to enhance the ability of the students to work collaboratively in groups and learn through teaching and being taught by their classmates, while playing a game. To evaluate the efficiency of the module, students were asked to respond to a survey regarding their experience with both traditional and cooperative learning styles. The results showed that students consistently prefer group over individual assignments. Moreover, students responded that group problem-solving enhanced and deepened their understanding of theories presented by the instructor. The role of the competition aspect of the approach was ambivalent, as perceived by students. The survey results suggest that it made problem-solving more engaging and enjoyable, but it was also a stressful experience for some students.

Keywords: Cooperative learning, Competition, Soil Mechanics, Education

1 Introduction

In the majority of universities around the world, engineering courses are still taught the same way they were taught decades ago. This classic method of teaching is mostly deductive, where the theory is presented first by the instructors, followed by example problems, the latter of which may in some cases be led by teaching-assistants during recitation hours. Also, sometimes students are given homework problems to solve individually in order to practice what they learnt in class. Students learn to follow specific procedures for solving problems, by mimicking the steps the instructors follow in the class. That way students tend to memorize methods for the exams (short-term) without truly incorporating this knowledge into their belief system (long-term) (Prince and Felder, 2006).

Alternative methods of teaching include inductive approaches, where students have a more active role in their learning. Numerous studies have highlighted the benefits of inductive methods in teaching engineering courses. According to Prince and Felder (2006), inductive methods include; a) inquiry-learning, b) discovery-learning, c) problem and project-based learning (PBL), d) case-based teaching, and e) just-in-time learning. The most traditional method of inductive teaching is inquiry-learning, where the instructor asks questions or poses problems and the students need to apply the methods they learnt, in order to find the solution (Bateman, 1990; Prince, 2004; Lee, 2012). Similarly, the discovery-learning approach involves questions or problems where students have to find the solution but without any directions or guidance by the instructor. The students work in a self-directed way and “discover” the desired factual and conceptual knowledge in the process, while the instructor simply provides feedback (Leonard, 1988; Westbrook and Rogers, 1994).

Problem-based and project-based learning (PBL) methods are similar to discovery-learning in the sense that students have to solve a problem while the instructor does not provide guidance but has the role of facilitator. However, in this case, students have to solve a real-world open-ended problem, and work in teams to develop a viable solution (Dahlgren, 2003; Weiss, 2003; De Graaf and Kolmos, 2003; Jensen et al., 2003). Case-based teaching, frequently seen in courses offered by business schools, is similar to problem-based learning, however the given problem/case, real or hypothetical, is more well-structured and with more details than the problem-based learning (Fitzgerald, 1995). Finally, the 'just-in-time teaching' (JITT) method combines web-based technology and active learning methods (Modesitt et al., 1999). It involves questions assigned to the students to answer online a few hours before the class, while the instructor reads through the answers and adjusts the lecture accordingly (just-in-time).

All inductive methods mentioned above rely on a fundamental principle; constructivism. Based on constructivism, individuals filter new information through mental structures that incorporate their prior knowledge and beliefs, and actively construct their own reality, independently of whether or not there is one objective reality (Biggs, 1996). When constructivism is applied in teaching, students construct knowledge for themselves, thus they have an absolute active role in the learning. To make constructivism effective, instructors should a) present new material making the connection with real-world applications and other areas of knowledge, b) encourage students to work inside their zone of proximal development, meaning the area between what they are capable of doing independently and in collaboration with more capable peers, c) require students to fill in gaps and extrapolate knowledge presented by instructors, and d) encourage students to work in groups.

Many educational studies and cognitive researches have shown that intellectual development, critical thinking and problem solving, essential skills to scientists and engineers, are promoted more efficiently through inductive than deductive teaching (Smith, 1996; Oliver-Hoyo et al., 2004; Oliver-Hoyo and Allen, 2005; Prince and Felder, 2006; 2007). However, although inductive teaching approaches can be more effective in helping students understand the concepts and retain information for longer, they don't necessarily guarantee student engagement throughout the length of the course.

Instructors in engineering design courses often adopt problem-based and project-based methods for teaching design methods, with the climax being the capstone project, where students have to use the skills and knowledge gained throughout the curriculum to work as a team on a real design project. One of the geotechnical engineering courses that follows the same teaching style is 'Foundation Design' course which is offered usually in the senior (fourth) year of civil engineering undergraduate studies. However, courses that focus more on theory, such as 'Soil Mechanics', are usually taught following more deductive methods (i.e. instructor teaches theory and shows application examples). Homework problem sets are typically assigned at the end of lessons or topics, so that students practice what they learnt in class.

This paper suggests an alternative way of teaching Soil Mechanics to junior level (third year) students, based on the principles of constructivism. To enhance student engagement in the course, the proposed approach incorporates cooperative learning and competition in the form of a game. Students competed on completing and submitting assignments, with bonus points accumulated for correct answers. The goals of the suggested teaching approach were to: a) enhance the ability of the students to work collaboratively in groups, both in and out of class, b) create an atmosphere of achievement, as students not only learned to apply theories themselves, but also through helping and interacting with other team members c) enhance the efficacy of problem solving in understanding of theories through collaborative learning, and d) encourage learning and engagement by incorporating a competitive component to the exercises, thereby simulating a game environment.

2 Alternative method of teaching Soil Mechanics

2.1 Suggested Educational Module

In the proposed educational module, class starts with lectures on Soil Mechanics concepts in the traditional deductive way. The instructor presents the theory and shows basic conceptual examples of applications but without solving complex problems. That way, students do not have a reference when they are asked to solve a problem, thus their process of thinking is not guided, but they are left unrestricted to 'construct' their own solution (*constructivism*).

The class is divided into groups of 3 to 5 students (depending on the size of the class), with the goal of creating heterogeneous groups including a mix of strong and weak students. If applicable, it is also desirable to have group heterogeneity in terms of gender and race. Students are encouraged to collaborate with their group members to solve the in-classroom problems, as well as the homework assignments. Specific roles are not assigned to group members; students are unrestricted to choose whether they will all work on the assignments a) collaboratively, b) individually and then compare their solutions, or c) have distinctive roles (*e.g.*, one student is leading the solution, others follow, etc.).

The goal of having heterogeneous groups is to enhance student team-work spirit even when they are working with people they are not used to, or they do not necessarily feel comfortable with. Also, students learn better by explaining their thought process while solving problems. Thus, strong students learn the concepts by guiding the solution and teaching their peers, while weaker students learn from participating in the discussion. Hopefully, this procedure will also help reserved students to feel more comfortable to take the lead in solving the problem, as they will be talking among peers in a small group, thereby mitigating the fear of making a mistake.

After a Soil Mechanics concept is completed in the lectures, the instructor gives an application problem to the student to solve in the classroom. To keep the class on track, a time limit should be set. Students have to pay attention throughout the lectures and use their critical thinking in order to apply the theory for solving the problem. To increase student engagement and keep them entertained, the teams have to work on the solution and compete with each other on submitting their correct answers as fast as possible, for the chance of getting extra points. The first team to submit their answer correctly, gets 5 extra points on that specific week's assignment (for a grade out of 100). The instructor has to evaluate their answer in the class and decide on the winning team. The majority of the problems assigned in class and as group homework assignments are adopted, with some modification, from soil mechanics textbooks (*e.g.,* Coduto et al., 2011; Budhu, 2015; Das and Sobhan, 2018), see Example 1 in Appendix A.

After the period of time allowed for solving the problem is completed, the instructor presents to the class the winning team's solution, and, if applicable, alternative correct solutions suggested by the other teams. The instructor can monitor the progress of groups, interact with group members to encourage participation, and address questions in guiding groups in their collective efforts to solve the problem. Through these interactions, the instructor can directly evaluate, in near real-time, student progress, and can identify topics to address in more detail as the lesson progresses. The role of the instructor is flexible, as providing some guidance, without directly answering the question, can be encouraging and give some confidence to the students, in addition to building personal rapport.

The same logic is applied for the homework assignments, see Example 2 in Appendix A, where students have to work again with their assigned group members to solve problems correctly and submit them as quickly as possible within a certain timeframe, having extra points as a reward. The extra points may be different each time, depending on the length and difficulty of the assignment. The use of an online submission system is suggested in order to designate a time stamp for each team's submission.

2.2 Application of the module

The suggested teaching module was implemented during the Spring semester of 2019, in two concurrent sections of Soil Mechanics class, taught by two different instructors. Despite the efforts of the instructors to apply the module the same way in both sections, personal teaching style may have affected the implementation of the method. To compare the efficacy of the suggested method and the students' preference compared with the traditional approach, the new module was applied only during the second half of the semester. To evaluate the effectiveness of the suggested educational approach on student learning and engagement, students responded to a survey regarding their experience with both traditional and cooperative learning styles near the end of the semester. Between the two sections, 32% were female and 68% were male students. A total of 50 junior-level (third year undergraduate) students from both sections participated, with 32% being female and 68% male. Demographic data regarding their race have also been recorded, although they have not been associated individually with each question, at this stage. Table 1 shows the race distribution of the participants.

Table 1. Race distribution of participating students

Caucasian	Hispanic or Latino	Asian or Asian American	Black	Other Race
60%	14%	12%	10%	4%

The students were asked to respond to a set of eight questions, four regarding their studying habits and their role in the group, before and after the application of the module, and four regarding their perception of the suggested module, using a system of five possible answers (strongly disagree, disagree, neutral, agree, strongly agree). Results of the student surveys conducted near the conclusion of the course are presented in the following section.

3 Student Responses

Broadly, the student feedback regarding the main features of the educational module, *i.e.*, working in groups, solving geotechnical problems in a game format, and competing, were positive, with a more favorable response toward the former two aspects of the educational module. Further inspection of the results revealed a number of noteworthy correlations, discussed next.

Students responded to questions regarding their preference to work individually or in groups when solving problems and studying for courses in an engineering curriculum. The results, shown in Figure 1a, suggests that prior to the experience of solving problems in groups and in a competitive game environment, a large number of students, almost 40%, were already studying with a group of friends, while 60% were working individually. This preference runs immediately counter to the majority of the activities throughout most courses in traditional civil engineering curricula, where students are assigned individual problems and assignments in the classroom, and are often required to work independently on assignments outside the classroom as well.

The gathered response in this survey instead favors allowing students to work in groups inside the classroom to solve problems, even at the junior and senior levels in college. The results also reveal that through working in groups, students' preferences shift from working individually to working in groups (Figure 1b). These preliminary results suggest that shifting from independent problem-solving activities and assignments, both inside and outside the classroom, can not only help students learn better, but also build their tendency and openness to working in a team, an important soft skill that employers increasingly demand from engineering graduates.

The above observations are further substantiated by student response to the following question: "*Which assignment mode would you prefer in order to enforce your learning*". The question was asked for in-class activities as well as for homework assignments. The results of the survey are shown in Figure 2. It can be seen that the majority of students responded that they prefer to work in groups, or to have a combination of group and individual activities, both inside and outside the classroom. Inside the classroom, student preference was overwhelmingly toward group activities, while outside the classroom students preferred to have at least some individual assignments in addition to group work. While further evidence is needed to conclude regarding efficacy of group activities inside and outside the classroom for civil engineering courses, these preliminary results support the design and delivery of education modules that follow the engaging game-format group-based activities investigated in this study.

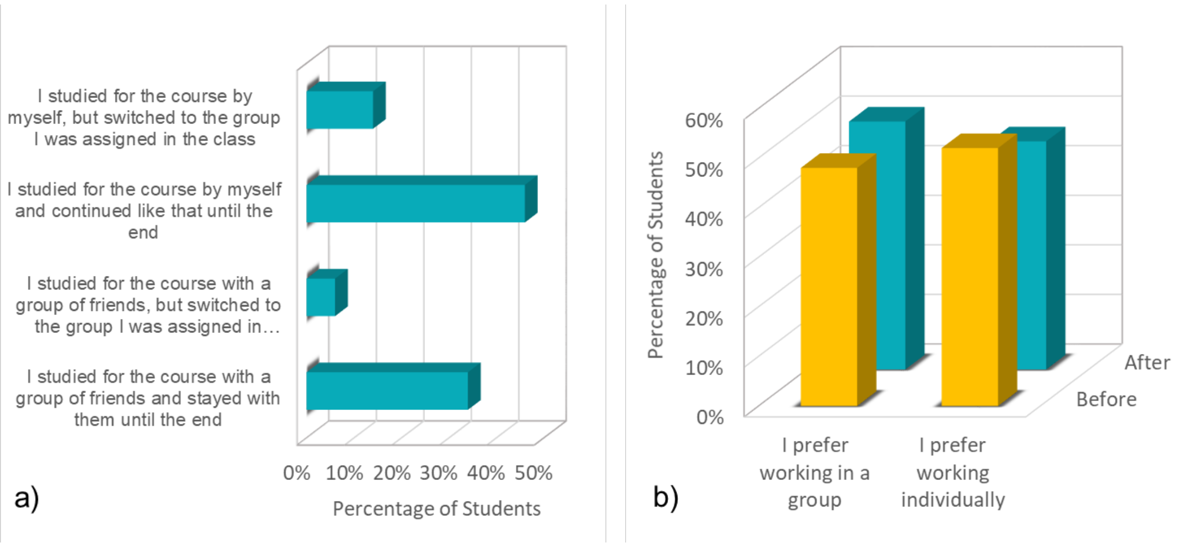

Figure 1. Survey results regarding student preferences to work individually or in groups

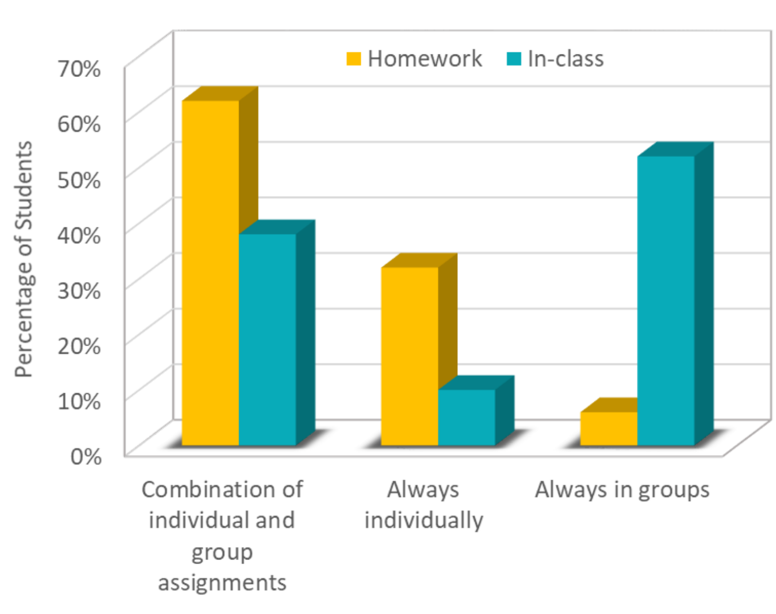

Figure 2. Students' preference for studying individually or in groups, inside and outside the classroom

Participation in group activities, as observed by the instructor and reported by students in the survey results shown in Figure 3, was divided. Approximately half of the students (48%) participated in solving problems, but worked individually toward the solution. The rest of the students (52%) reported either leading other group members, following their peers, or working collaboratively to solve the assigned problems. These initial observations were further analyzed by separating responses according to race and gender. The authors have data revealing that participation in group activities correlates moderately with race, and strongly with gender. This data is outside the scope of this research and are excluded from the current paper.

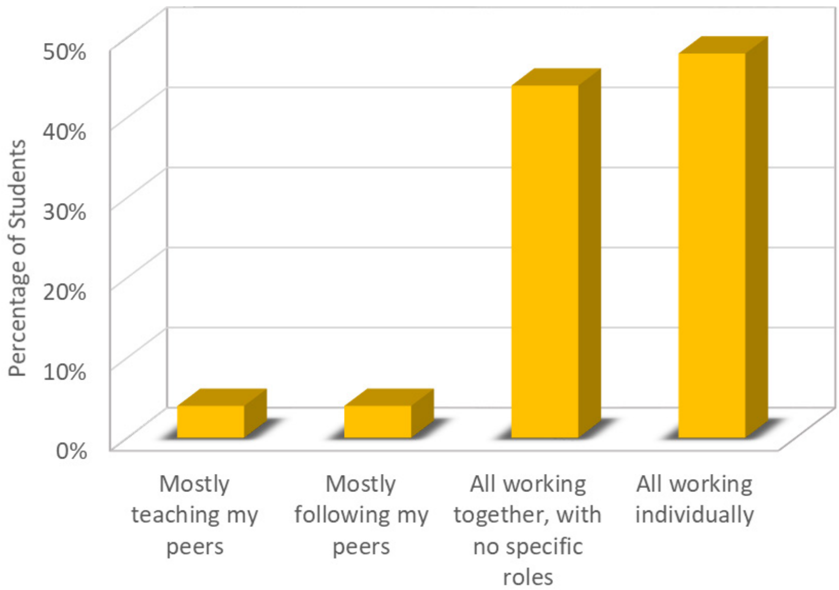

Figure 3. Students' responses regarding their role in the study group

As stated above, the '*game'* aspect was introduced to make learning and problem-solving more engaging and enjoyable. Students had to compete with each other to submit their answers to the assigned problems, correct and fast, with a reward of extra points. In the end, students were asked to say with which statement they could relate the most, regarding the competition aspect of this educational module. Figure 4 shows that a sizeable percentage of students (43%) were excited and studied more because of the extra points they could get. Although the goal was to make the homework and in-classroom assignments more enjoyable by applying a game-format, some students (33%) perceived it more as competitive and thus stressful. This finding aligns with the results from another survey on senior (fourth year undergraduate) students who were introduced to a competitive collaborative educational module for design courses (Ieronymaki, 2019). Finally, about 24% of the student body remained indifferent.

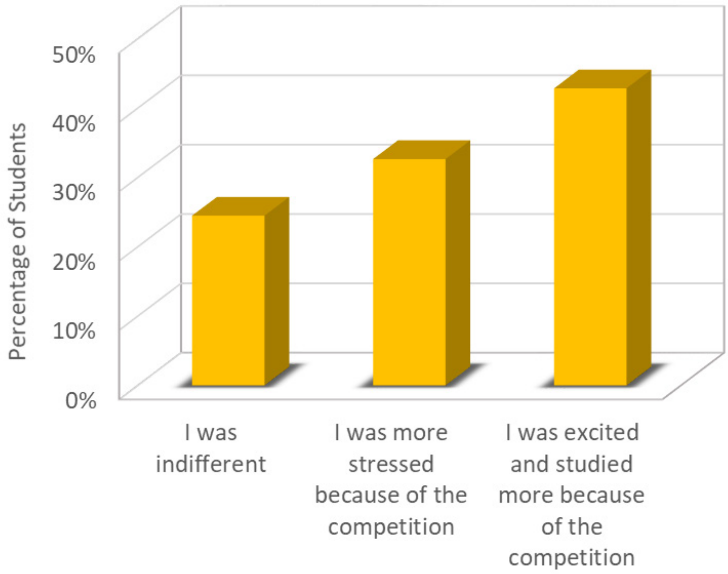

Figure 4. Students' responses on their perception regarding the '*game*' (extra points)

An additional question was posed to assess whether the game-aspect of the approach made the whole course more enjoyable/fun. As presented in Table 2, the majority of the students responded positively with about 52% in the strongly agree and agree category. About 38% remained neutral, while only 10% of the students responded that the competition did not enhance the fun aspect of the course. The results are not in contrast with the previous question, because the course can be more fun with the game-aspect rather than without it, even though it may be a stressful factor for the students.

Table 2. Students' response regarding the competition

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Competing with other groups to solve problems made the class more fun (enjoyable)	24%	28%	38%	6%	4%

The students' perception on the game we introduced depends on two main factors; 1) the attitude a person has towards competition in general (*i.e.*, how more or less competitive a person is) and 2) the way the game is implemented in the course. The first factor cannot be controlled by the instructor as it depends on the student's personality. However, the game can be adjusted to make it less stressful, by changing the reward system or by removing the time factor. This may result in making the course more fun as the game aspect is maintained, while the stressful component of competition is rendered less prominent.

Two survey questions assessed the efficacy of group activities in enhancing students' learning of engineering concepts, the results of which are presented in Table 3. When asked whether group assignments helped students learn the concepts better, the majority of students responded positively, with 53% of the responses in the strongly agree and agree categories. However, students did not agree as strongly that group assignments helped them learn faster (39%). This suggests that while they enjoy the game component, students do not respond well to time-constrained activities, which can induce anxiety and can distract from the learning process (Ieronymaki, 2019).

Table 3. Students' summarized response to the survey

		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The group assignments helped me learn the concepts	Better	24%	29%	11%	9%	3%
	Faster	12%	27%	33%	22%	6%

It is evident from Figure 5, that the majority of students (67%) considered the suggested module as helpful to their learning. Students responded that working in groups helped them learn concepts better by: 1) teaching concepts to their peers, 2) learning concepts from peers in their group, and 3) by a combination of learning from their peers and helping others in their group in different activities. 33% of students reported that working in groups did not help them at all. These responses provide direct evidence on the benefits of group activities in enhancing student learning of engineering concepts.

Although the *game* aspect enhances the 'fun' level of the course, it can affect the length of the lecture, and thus the amount of material that can be covered in a lecture. However, the authors found that with the suggested educational approach, fewer examples were needed in class in order to achieve the desired level of comprehension for the concepts taught. Therefore, the overall length of the lectures remained practically unaffected.

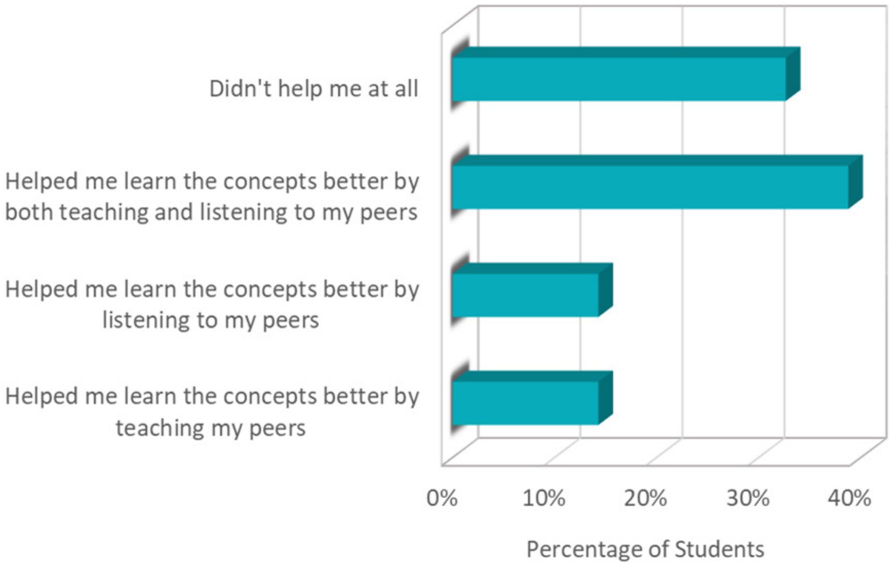

Figure 5. Students' responses regarding the efficacy of group activities in enhancing student learning

4 Conclusions

In this study, a novel educational module was proposed for undergraduate education in civil engineering courses. The module was developed for the soil mechanics course at the junior level, and can be implemented in other similar courses. Cooperative learning and game environment learning were incorporated into a traditional course structure, to encourage inductive learning. Students worked in groups to solve problems, and competed to submit correct answers. The goals of the suggested teaching approach were to: a) enhance the ability of the students to work collaboratively in groups, both in and out of class, b) create an atmosphere of achievement, as students not only learned to apply theories themselves, but also through helping and interacting with other team members, c) enhance the efficacy of problem solving in understanding of theories through collaborative learning, and d) encourage learning and engagement by incorporating a competitive component to the exercises, thereby simulating a game environment.

Students were asked questions regarding their experience with both the cooperative teaching approach, and the traditional deductive approach. Analysis of the responses revealed that the educational module encouraged students to participate in cooperative learning, by helping others in their group, and by working collaboratively on solving problems. Moreover, it was found that incorporating a game component increased effective participation in the module, while the competitive nature of the game received mixed reactions. Students found the competitive nature of some of the problems to be stressful, thereby hindering the learning experience. The preliminary findings of this study therefore suggest that cooperative learning can be effectively implemented using the educational module proposed, but with a game component that places less emphasis on competition, and more on collaboration.

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Appendix A: Examples of in class and out of class group activities

Example 1: In class group activity

Topic: Effective stress principle.

Instructor introduces the effective stress principle, and solves an illustrative example with students. The instructor leads solving this introductory example. Instructor alerts students that the next problem is a group problem. The problem is introduced, and a brief overview of the solution strategy is given by the instructor. The students are given 10 minutes to work in their groups on the solution. Students gather in their groups, and work on the solution.

Problem Statement: In the soil profile shown, the GWT fluctuates seasonally within the sand layer due to precipitation. Calculate the depth of the GWT from the ground surface, Z, which will result in a vertical effective stress at point A equal to 2700 psf.

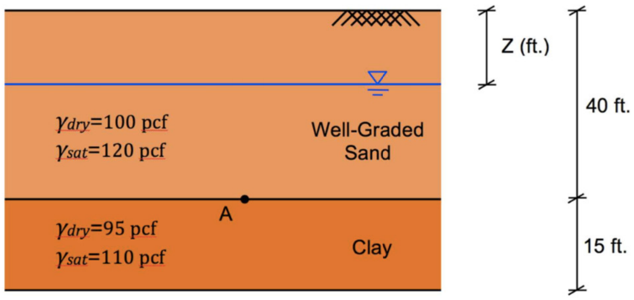

Figure A1. Soil profile for in-class group assignment

The instructor walks around the classroom, and checks the progress of groups. The remaining time is announced twice throughout the 10-minute period. As groups announce their solution, the instructor inspects the solution with the group. If the solution is correct, he/she records both that the correct solution has been obtained, as well as the time. If the solution is incorrect, the instructor hints to the mistake, and allows students to continue to work on the solution.

At the conclusion of the 10-minute time allocated to the problem, the instructor asks the groups with the correct solution to participate in reviewing the problem solution with the class. Another five minutes is allocated to this task. There are ten such in-class group problems throughout the semester, along with a total of 20 out of class problems in the form of group problem sets. The progress of the groups is monitored and intermittently shared with the student to encourage competition among groups.

Example 2: Homework group activity

Topic: Rate of Consolidation.

Instructor introduces the rate of consolidation concept in class, and solves an illustrative example. A problem set with 4-5 problems is assigned that requires students to work in groups at home and submit their solutions on an online system (Moodle), with a cut-off of 1 week from the day of the assignment.

Each group submission gets a time stamp when it is uploaded and the first group that submitted their answers first and correct, get the extra points (*e.g.*, +5 points, out of 100). The instructor announces which group gets the extra points when the problem sets get corrected. The following example is an example problem of the 'Rate of consolidation' problem set (Coduto et al., 2011).

Problem Statement: A shopping center is to be built on the fill shown in Figure A2. The proposed buildings and other facilities can tolerate a settlement due to the weight of the fill of no more than 2 in. Therefore, once the fill has been placed, it will be necessary to wait until enough settlement has occurred that the remaining settlement will be less than 2 in. Only then may the building construction begin. Assuming the fill will be placed at a uniform rate from May 1 to June 1, determine the earliest start date for the building construction. For this problem, consider only settlement due to the weight of the fill.

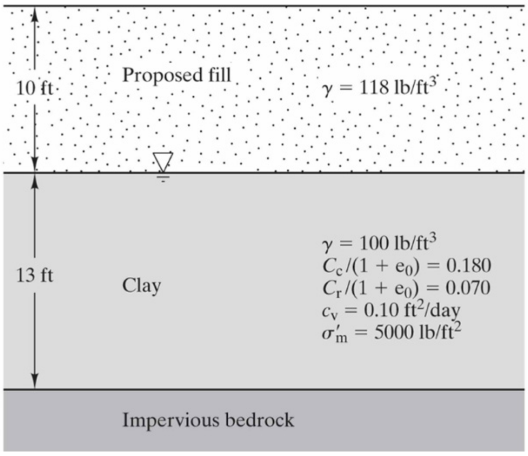

Figure A2. Soil profile for homework group activity (after Coduto et al., 2011)

Authors' bios

Evangelia S. Ieronymaki, Manhattan College New York, USA

Eva Ieronymaki is an Assistant Professor of Geotechnical Engineering at Manhattan College New York, in the department of Civil and Environmental Engineering. She holds B.Sc. and M.Sc. degrees in Civil Engineering from the National Technical University of Athens (NTUA), Greece, and S.M. and Ph.D. degrees in Geotechnical and Geo-environmental Engineering from the Massachusetts Institute of Technology (MIT), USA. Her research deals primarily with numerical modeling, data analysis, tunneling, deep excavations and soil-structure interaction. Eva is also involved in engineering education research, investigating new methods for effective learning and engagement in junior and senior level courses of geotechnical engineering. She has received several prizes and awards, including DFI Women in Deep Foundations award (2017). Her research on teaching effectively foundation design courses drew the attention of the industry, and her work was featured in the Deep Foundations Institute magazine (January/February 2020).

Mehdi Omidvar, Manhattan College New York, USA

Dr. Mehdi Omidvar is an assistant professor at Manhattan College who specializes in the field of Geotechnical Engineering. He holds his Civil Engineering degree from New York University. His disciplinary research interests involve natural hazard mitigation, monitoring, and risk assessment applied to bridge scour. His team is developing tools for using autonomous underwater vehicles in bridge scour monitoring. Dr. Omidvar also specializes in experimental, analytical, and constitutive modeling applied to high strain rate loading and soil-structure interaction problems. He has received funding from the US Department of Transportation, and the Department of Defense, through the Strategic Environmental Research and Development Program. Dr. Omidvar is also a passionate and innovative educator. He has developed classroom modules to visualize modes of failure to aid limit equilibrium analysis of foundations and earth retaining walls, with funding from the United States Universities Council on Geotechnical Education and Research (USUCGER). He is also currently leading research on collaborative learning in geotechnical engineering classes. Dr. Omidvar is a past participant of the Excellence in Civil Engineering Education (ExCEEd), and the USUCGER Teaching Strategies and Resources Workshop.

Danielle Rabadi, Manhattan College New York, USA

Danielle Rabadi, E.I.T., is a graduate Civil Engineer with a minor in Mathematics from Manhattan College Class of 2020. She was an active student in her school as she has taken on several leadership positions throughout her college career, including: President of Structural Engineers Association of NY, Co-Project Manager for Concrete Canoe, Treasurer for DFI, and Vice-President for Society of Physics Students. For a year and a half she worked as a Teacher's Assistant for the Civil Engineering Department at MC where she set up labs for the Earth Science for Engineers course, as well as helped students study for their course work. Her previous internship involved working for Mueser Rutledge Consulting Engineers (MRCE). During the course of her internship, she collected and categorized site boring samples, and performed a rough cost analysis for a water-front project. She holds her OSHA 30-hour Construction Safety and Health certification. She is also a member of Chi Epsilon Honor Society and a (to be inducted) member of the Order of the Engineer, and was awarded the Vincent DeSimone Scholarship by the Concrete Industry Foundation.

Feedback to Students on Soil Mechanics Laboratory Reports – Why Use Virtual Technology if you Can Have a Productive Real Dialogue?

M. Pinho-Lopes[1,2] & W. Powrie[2]

[1]*University of Aveiro, Aveiro, Portugal*
mlopes@ua.pt

[2]*University of Southampton, Southampton, UK*
m.pinho-lopes@soton.ac.uk, wp@soton.ac.uk

ABSTRACT: Soil mechanics is often perceived by undergraduate students as difficult. This paper describes an approach (method and rationale) to providing individual feedback on laboratory test reports based on small (one instructor to two students) groups. Changes in response to student comments are discussed, and the benefits to students and instructors assessed. It is concluded that this is an effective, efficient, and rewarding way of encouraging learning, engagement and developing understanding.

Keywords: Soil mechanics, Assessment for learning, Feedback, Laboratory work, Student-instructor interaction

1 Introduction

Soil mechanics courses can be challenging for students. Conceptual difficulty is often associated with the two- or three- phase nature of soils, and the requirement for (and linkages between) three state variables of shear stress, normal effective stress and specific volume. Understanding and deep learning are essential if students are to achieve the intended learning outcomes.

Assessment design should focus on promoting student learning at various levels, including discipline and subject level, professional competencies, generic literacies and skills (HEA, 2016). Assessment tends to shape what students study, when they study, how much work they do and their approach to learning (HEA, 2012). Thus improving assessment is a key factor for improving student learning. However, according to Price et al. (2011), assessment often does not support learning because of ineffective feedback. Hence feedback is one of the most powerful strategies to improve learning and achievement (Hattie, 2009). More importantly, the quality (rather than the quantity) of feedback is essential for feedback to be received and used by the learner (Brooks et al., 2019). Assessment tasks and assessment feedback should focus on engaging students in an effective learning experience.

Good (1978) suggested marking examination scripts with the student present, but this approach is rarely adopted. More recently, Chalmers et al. (2018) investigated whether a one-to-one meeting between an instructor and a student would be a better use of time than the instructor marking and writing feedback on a short essay. Chalmers et al. (2018) report that both instructors and students considered the face-to-face feedback positive and beneficial, enabling a feedback dialogue and that the marks given could be explained and justified by the instructors. This paper reports on the use of face to face, small group feedback sessions to promote learning in soil mechanics at the University of Southampton (UK).

2 Assessment and feedback in Higher Education

2.1 Assessment and feedback

In their review of literature on assessment and feedback in higher education, Jackel et al. (2017) identify the following fundamental principles and subject categories: assessment for learning; aligned and fit-for-purpose assessment; collaborative construction of standards; integrating assessment literacy with learning; defensibility of professional judgments; and the limits of assessment.

Traditionally, assessment *for* learning has been associated with formative, and assessment *of* learning with summative assessment. HEA (2012) highlights the formative and diagnostic characteristics of assessment for learning, which allow adjustment of teaching and learning activities to the needs of students. This leads to dialogic feedback processes that can be highly beneficial, particularly when regularly embedded in learning activities. Nonetheless, assessment can be simultaneously summative and formative. For example, Bennett (2011) suggests that a piece of coursework and a final examination both have strong formative components, as they drive learning during the course (what and how it is learned), and feed forward into future learning. While the primary focus of a summative assessment is what students know and can do, a properly designed summative assessment will also support learning.

Assessment and feedback should be in constructive alignment, linking the learning objectives, the teaching and learning strategies and valid, relevant and authentic tasks, and thus fit for purpose (Jackel et al., 2017). However, defining learning outcomes, assessment criteria and providing written feedback cannot replace instructor-student interaction, and some groups of students will need such contact more than others (HEA, 2012).

Clearly articulated assessment and feedback standards contribute to improving transparency of assessment and student learning, particularly when students engage with setting those standards (Hendri et al., 2012; Jackel et al., 2017). Such engagement can be promoted by integrating assessment literacy into course design (HEA, 2016); developing assessment literacy amongst academics is also key (Price et al., 2011). Marking assessment tasks requires professional judgment, and creating opportunities for critical reflection within a collaborative setting can contribute to improving the transparency and fairness of these (Bloxham et al., 2016). In any case, assessment has limitations and lacks precision. Some aspects of learning cannot be reasonably assessed; the scope of assessment tasks may go beyond and above the intended learning outcomes; and any attempt to define and list all important competencies or learning outcomes is reductive (Jackel et al., 2017).

What exactly is feedback? Willis and Webb (2010) define it as “the range of processes whereby a student or group of students receives information about how well they understand concepts and are progressing with their studies”. But feedback should also include advice for action (Whitelock, 2010), allowing students to adjust and improve to meet the intended learning outcomes (Cowan, 2003). Evans (2013) reports different definitions of assessment feedback and distinguishes between a cognitivist view (feedback is seen as corrective) and a socio-constructivist view (feedback is facilitative by providing comments and suggestions and using dialogue to promote new understandings, which can lead to the development of communities of practice).

Student dissatisfaction with feedback in higher education has been widely reported, related to timing, content, organisation of assignment activities, and lack of clarity about requirements (Evans, 2013). There is also evidence (Gibbs and Simpson, 2005) that a significant number of students do not check their written assignment feedback upon receiving their marks.

Gibbs and Simpson (2005) presented 10 "conditions under which assessment supports students’ learning", seven of which refer to feedback:

1. “Sufficient feedback is provided, both often enough and in enough detail.
2. The feedback focuses on students’ performance, on their learning and on actions under the students’ control, rather than on the students themselves and on their characteristics.
3. The feedback is timely in that it is received by students while it still matters to them and in time for them to pay attention to further learning or receive further assistance.
4. Feedback is appropriate to the purpose of the assignment and to its criteria for success.
5. Feedback is appropriate in relation to students’ understanding of what they are meant to be doing.
6. Feedback is received and attended to.
7. Feedback is acted upon by the student”.

2.2 Effective feedback

Nicol and Macfarlane-Dick (2006) define good feedback practice as that which strengthens students' capacity to self-regulate their performance and put forward seven principles for good feedback practice:

1. Helps clarify what good performance is (goals, criteria, and expected standards).
2. Facilitates the development of self-assessment (reflection) in learning.
3. Delivers high quality information to students about their learning.
4. Encourages instructor and peer dialogue around learning.
5. Encourages positive motivational beliefs and self-esteem.
6. Provides opportunities to close the gap between current and desired performance.
7. Provides information to instructors that can be used to help shape the teaching.

However, some authors point out that these principles emphasise one side of the feedback process, with the main focus on the instructor (Dunworth and Sanchez, 2016). Hattie and Timperley (2007) proposed a model of feedback that includes the learner's perspective, posing three questions that need to be answered for effective feedback:

1. Where am I going (the goals) – "Feed up".
2. How am I going? – "Feed back".
3. Where to next? – "Feed forward".

Each feedback question may work at four different levels (Hattie and Timperley, 2007): task (how well tasks are understood or performed); process (the main processes needed to understand or perform the tasks); self-regulation (self-monitoring, directing and regulating of actions); self (personal evaluations and, usually, positive effect on the learner).

Feedback is an interactive process (Dunworth and Sanchez, 2016) of learning in a context of social interaction, hence dialogic. However, De Nisi and Kluger (2000) point out that feedback is received differently depending on the affective dimension of feedback, emphasising that feedback should focus on the task assessed and task performance. Neither the process nor the content should threaten the ego of the recipient, and guidance on how performance may be improved should not denigrate the performance of others. To make good use of feedback, students need to learn how to interpret feedback, how to link it to their own work, and how to improve their work in the future (Boud and Molloy, 2013).

Effective feedback needs an 'orientational' and a 'transformational' purpose, and an 'interpersonal' dimension (HEA, 2016). To meet these requirements, feedback should make student performance and achievement clear; feed forward by creating opportunities for reflection, improvement and increased student autonomy; promote student confidence and motivation; and build strong instructor-student relationships. Thus the learner should be at the centre of the feedback process and feedback comments should be (Ryan et al., 2019) detailed, i.e., sufficiently comprehensive for learners to know how their future work can be improved; personalised, i.e., responding directly to the individual student and the piece of work being assessed; and usable.

2.3 Feedback practices

Evans (2013) summarises practices from the literature to promote effective feedback, relating to the delivery, form and context of feedback. These include varying the mode of feedback, adapted to the task in hand and addressing the individual needs of the student. Immediate and delayed feedback can both be useful. Group discussions are beneficial, but students seem to like individual feedback. The purpose and the challenges associated with different feedback modes, including face-to-face dialogue, handwritten notes, rubrics and digital recordings, are varied and can influence the level of detail, personalisation and usability of feedback information (Ryan et al., 2019).

Face-to-face feedback is considered the best mode of feedback (Ryan et al., 2019). Synchronous feedback dialogues allow students to engage in conversation with the instructor, co-creating meaning and learning while representing and justifying their knowledge on a topic. However, these dialogues are ephemeral and may be difficult to set up for large cohorts (Ryan et al., 2019). Instructor-student dialogue is important in helping students to understand assessment expectations and learn how to use feedback (HEA, 2012). Nonetheless, while evidence from the literature indicates that replacing instructor-student dialogue with greater guidance or more detailed written feedback has limited impact on learning and achievement, many students expect written comments on their assessment tasks (HEA, 2012).

Feedback using audio, video or screencast recordings has been presented as an alternative to face-to-face feedback and to written comments: Ryan et al. (2019) cite authors who consider face-to-face feedback more efficient than written comments. Recordings can be revisited by students many times and may include a range of indications (e.g. tone, pace, body language, expression) perceived by students to be better at promoting understanding than written comments (Ryan et al., 2019). On the other hand, automated feedback is mostly a monologue with a focus on content delivery (Evans, 2013). Several authors report the use of technology-enhanced approaches to improve assessment and feedback. Suitable tools can help provide automated or speedier feedback, student-student and instructor-student dialogue, and support for peer and group assessment (HEA, 2012). However, technology is just an enabler and the pedagogy and the design adopted are essential for the success of assessment and feedback with technology enhancement (Gilbert et al., 2011).

Feedback can be delivered in different ways including individually, in a small group or a lecture class (HEA, 2012). Although students seem to prefer individual to group feedback, some studies highlight the benefits of group discussion (Evans, 2013). Immediate feedback seems to be more effective than delayed feedback (Morgan et al., 2014). However, tasks well within the learner's capability and where transfer to other contexts is important may benefit from delayed feedback (Evans, 2013). Either way, feedback should be given when there is still time for the student to act on it to improve their performance (Nicol and MacFarlane-Dick, 2006; Sadler, 1989). To improve students' satisfaction with assessment, better and more inclusive assessment methods are needed. These should be combined with strategies to promote instructor-student and student-student dialogue, ensuring that the timing, form and delivery mode of feedback allows students to learn from it and use it in their future work (HEA, 2012).

2.4 Face-to-face feedback

Race (2004) summarised key features of face-to-face feedback, highlighting its memorable and transformational nature for students. Body language, facial expression, tone of voice and the emphasis given by the instructor are additional dimensions of face-to-face feedback that complement verbal explanations. Race (2004) also discussed the advantages and disadvantages of this mode of feedback from the instructor perspective. The main advantages are: the personal, intimate and authoritative character of feedback; it enables addressing the students' needs, strengths and weaknesses individually; usually it is quicker than to write or type; it is a feedback mechanism appreciated by external reviewers (although it needs to be supported by evidence from the students).

According to Race (2004), the main disadvantages of individual face-to-face feedback include some students feeling threatened by critical feedback, which may lead to defensive attitude from students and a consequent harder reaction from the instructor; some students being embarrassed by praise and thus not fully benefiting from it; the time spent organising appointments, which with a large cohort can be high; instructor time wasted through missed appointments; students' confidence may be shaken by criticisms in a face-to-face session and they may tend to remember only such criticisms; the impracticality of keeping track of the feedback given to individual students (although this is arguably the students' responsibility).

3 Case study

This paper reports a feedback strategy implemented in a soil mechanics course at the University of Southampton (UK) since 2016/2017. The following sections include information on the course, the traditional feedback practices used and the changes implemented, as well as the methods used to assess the students' opinions and perceptions of the changes described herein.

3.1 Soil mechanics at the University of Southampton

The soil mechanics course forming the case study is followed by all second year students on the BEng and MEng programmes in Civil Engineering, MEng in Civil and Environmental Engineering, and MEng in Civil Engineering and Architecture. In the first year of these programmes, students take a course on civil engineering fundamentals that includes a Semester 2 module on geology for engineers. Geology for engineers is a pre-requisite for the second year soil mechanics course, and covers:

1. The structure of the earth, plate tectonics, continental drift and their engineering implications.

2. Geohazards and geotechnical risks.
3. The origins, distribution and variability of a range of geomaterials.
4. Properties of geomaterials with importance for construction.
5. Groundwater.
6. Effective stress and Mohr's circles.
7. Laboratory classes: Engineering description of soils and rocks; Classification of soils.

In Semester 2 of the second year, students take the soil mechanics course, which covers:

1. Revision and application of basic concepts, such as phase relationships and effective stress.
2. Groundwater, permeability and seepage: Darcy's law and concept of permeability; permeability measurement; flownet sketching, application of flownets.
3. Compression and consolidation: the oedometer test; one-dimensional compression and consolidation; application to field problems.
4. Soil strength and soil behaviour: soil as a frictional material; shear box tests; critical states; peak strengths and dilation; undrained shear strength of clay soils; the triaxial test apparatus; stress parameters; isotropic compression and swelling; shear tests; the Cam Clay model framework.
5. Calculation of soil settlement: selection of "elastic" parameters, Newmark's chart.
6. Retaining walls: concepts of engineering plasticity; active and passive pressures; stress field (Rankine) solutions for embedded walls; limit equilibrium (Coulomb) solutions for gravity walls; simple practical applications assuming frictionless and dry (no porewater pressures) conditions.
7. Foundations: stress field and mechanism solutions for idealised strip footings; bearing capacity factors for simple strip footing.
8. Slopes: the infinite slope; Taylor's charts.

Each semester has 12 teaching weeks. The contact time in soil mechanics comprises 36 hours of lectures and 2 laboratory sessions (3 hours each). All students must attend the laboratory sessions. Working in groups of 2 (occasionally 3), students carry out an oedometer test in the first session and a triaxial test in the second. Students prepare and submit an individual report for each laboratory test. The reports combined contribute 20% of the final mark for the course (10% per report); there is also a final exam (contributing 80% of the final mark). The laboratory sheets, made available to students at the start of the semester, include a description of the experiment and questions to be answered in the report.

The laboratory sessions and reports have several objectives: to carry out the experiment; to derive relevant information from the laboratory test data; to analyse and interpret the results and apply them to a real problem; to write up the report; and to develop and be able to demonstrate understanding.

3.2 Previous model

Before the changes reported in this paper, students submitted a hard copy of each of the two laboratory reports, prepared individually. Students were expected to write a description of the experiment, present their raw data, carry out and present calculations to evaluate relevant parameters, plot appropriate graphs, and answer various questions by way of analysis and discussion. On one day each week, students went in groups of about 10 to the geotechnical laboratory for a 3 hour laboratory session. Often 3 or more weeks were necessary for all students to complete one laboratory session. Marking only started after all of the laboratory reports had been submitted. The second laboratory session (triaxial test) was often affected by the Easter break (4 weeks), and some of the groups had their laboratory session after that break (near the end of the teaching period and coinciding with summative assessment tasks for other courses). This was a frequent cause of dissatisfaction amongst students.

After all of the individual reports for a particular laboratory experiment had been submitted, they were marked (by the laboratory demonstrators, supervised by one of the instructors who also moderated the marks); individual comments and feedback were included on the hard copy of each report. A marking *proforma* listing common mistakes was filled in by the markers, identifying areas where students in general lost marks. After marking all the reports, the marks were moderated. Only then were the final marks and corresponding individual feedback made available, by returning the hard copies of the report and the marking *proforma* to the students. In addition, generic feedback on the coursework was made available to all students, via the University's e-learning platform. For classes of 50-75 students, the whole process usually took 3-5 weeks for each of the two laboratory experiments.

3.3 New model

The strategy implemented and reported herein attempted to address students' concerns about the time lag between submission of coursework and the availability of the marks and feedback, as well as the lateness of some of the laboratory sessions (taking place after the Easter break). At the same time and probably more importantly, the authors aimed to promote effective feedback through assessment and feedback *for*, rather than *of*, learning. Thus in 2016/2017, the authors changed the timings of the laboratory sessions, implemented a new feedback strategy and took on the marking. As before, students were divided into groups (~10 students) and attended two laboratory sessions: the first on the oedometer test and the second on the triaxial test. Students carried out the experiment generally in pairs. They collected their own data, and where necessary (e.g. for the triaxial test, in which each pair of students carried out the test at a single cell pressure but data from tests at three cell pressures were needed for the write-up), the data were shared within each main laboratory group. Students then had two weeks to analyse the data, answer the questions on the laboratory sheet and prepare an individual report.

Two significant changes were implemented at this stage. First, on the day of submission (two weeks after the corresponding laboratory session), students submitted a soft copy of their report via the e-learning system. Secondly, and usually on the day of submission, students met one of the instructors in small groups of one instructor and usually two students for a face-to-face feedback session. During that session, students answered questions on the coursework, explained how they had addressed the different questions on the laboratory sheet and discussed their main conclusions. The instructor could identify knowledge gaps and point out areas for further study, and link the results to realistic contexts. Feedback was verbal, although the instructors sometimes wrote short comments on the reports.

Reports were marked to the nearest 10% against a published list of objective benchmarks, as follows:

- missing the laboratory session, 0%
- attendance at the laboratory session and no report submission, 20%
- data are presented and processed but no discussion is included, 40%
- minor mistakes, inconsistencies or incompleteness (e.g., a significant error in the calculations, or an element of the write up missing or wrong), 60%
- complete and substantially correct and well presented report, 80%
- exemplary in every way, 100%.

The criteria were defined to ensure that students doing the minimum, i.e., attending the lab and submitting data and most calculations would receive the pass mark (40%).

To ensure that all laboratory sessions took place before the Easter break, it was necessary to schedule more sessions each week. This had to be managed to avoid scheduling conflicts with the engineering geology laboratory sessions for Year 1 students, which took place in the same laboratory. It was also necessary to start the oedometer laboratory sessions before the lectures on the topic. To ensure students would go into the laboratory adequately prepared, introductory videos were created and made available to students to explain the experiment, familiarise students with the equipment and give an overview of the whole experiment and its objectives.

The feedback sessions were timetabled to ensure all students could attend them. Each feedback session was allocated a 15 minute slot. In 2016/2017, owing to the timing of Easter, students carried out the triaxial test before the Easter break; the report was submitted within two weeks (during the Easter break) and the feedback sessions took place when teaching resumed. The motivation for the changes and the process as a whole were explained in detail to students at the start of the semester.

3.4 Assessment of the model implemented

Different approaches were used to assess the impact of these changes on students and their perceptions on the course. These included the staff-student liaison committee of the Civil and Environmental programmes at the University of Southampton that meets regularly, and is attended by the Director of Programmes and Programme Leads as well as by student representatives. The student representatives (at least one per year of the programme) collect their peers' perceptions on the courses in that year; good features of the courses are highlighted and areas for improvement are discussed. That information was used by the authors to assess the satisfaction of students with the new model.

In addition, for each course a short mid-semester evaluation (typically during the sixth week of teaching) was carried out. During a lecture, students were asked to fill in three open questions on the course:

- "STOP. Tell us what you don't like about the current course (and WHY).
- START. Tell us what improvements you would like to see made to the course (and WHY).
- CARRY ON. Tell us what you like best about the course (and WHY)."

Students wrote their answers on the forms distributed, which were then analysed by one instructor. During the subsequent lecture, the instructor summarised the comments received and explained how the issues raised would be addressed during the second part of the semester or the following year.

4 Discussion

The face-to-face feedback sessions have been used over the last three years (between 2016/2017 and 2018/2019) both to mark and give feedback on the laboratory reports. In 2016/2017, after the oedometer test feedback session, some students raised issues and suggested improvements. Where possible, those issues were addressed in the second laboratory experiment and its feedback session. The remaining issues were addressed in the following year. Section 4.1 discusses some of the points raised by students during the first year of implementation and the improvements made to address them. Section 4.2 discusses how students have reacted to the improved version of the approach.

4.1 First year of implementation

As mentioned earlier, the face-to-face feedback sessions were implemented for the first time in 2016/2017 and the motivation for the change was explained to the whole class at the start. After the oedometer test feedback session, it was clear that most students liked the new mode of feedback. Some students felt that the two instructors marked the reports differently. Although that was not the case, to ensure that the published criteria were adhered to, students were given an indicative mark for their report during the face-to-face feedback sessions. Later, the instructors met to review and agree the final marks. This process, termed "moderation", involved comparison of the indicative marks across the range of students and both instructors, to ensure consistency in that similar reports and outcomes were given the same final mark. Marks were not scaled to fit any pre-determined distribution.

In 2016/2017, 74 students took the soil mechanics course, of which 39 answered the mid-semester course evaluation form. Some responses were related to the laboratory classes and feedback sessions: 15 students found the face-to-face feedback sessions positive; 6 students asked for the content to be covered in lectures before the corresponding laboratory session; 4 students indicated they would prefer the instructors to take more time to mark the reports; 1 student reported feeling intimidated during the feedback session. Although very few students were unhappy with the face-to-face feedback sessions, the instructors wanted to address their concerns; hence the causes of dissatisfaction were investigated.

Owing to the timing of the sessions and the order of the syllabus, students had to carry out the oedometer laboratory test before the lectures on that topic. Some feedback sessions occurred after a week of lectures on the topic, which other students felt was unfair as the lectures had included application exercises. For the second laboratory test, timing relative to lectures was not an issue.

Some students disregarded the instructions on how to prepare the laboratory report and included – unnecessarily – long descriptions of the test procedure. These were not marked as students had been asked specifically not to include them. The allocated time per face-to-face feedback session (15 minutes per group of two students) was clearly not enough, as many sessions over-ran. Nonetheless, the instructors were able to identify mistakes rapidly during the feedback sessions, without having to check all the calculations in detail. This seemed to faze some students, who perceived that the instructors were not giving their reports "full attention". The atmosphere of the face-to-face feedback sessions was informal and constructive, similar to a conversation, but one student interpreted the feedback session as a *viva voce* and felt intimidated.

After the first round of face-to-face feedback sessions and during one of the lectures, one of the instructors explained again the goal of these sessions and how they were organised. The face-to-face feedback sessions aimed to give students quick, personal feedback on their work, identifying areas where more revision was necessary and promoting the ability to critically analyse the results and link theory and practice. In addition, the instructor showed some anonymised excerpts from laboratory reports, explaining how some mistakes were easily spotted and how students could easily adopt similar strategies when reviewing their work, revising for the exams and later in professional practice. It was highlighted that the instructors could usually rapidly check a student's work without having to repeat the calculations in detail. In addition, each face-to-face feedback session was extended to 30 minutes per group of two students. These discussions and changes seemed to satisfy most students.

During the second round of face-to-face feedback sessions, it was clear that students had read the coursework brief and addressed it, eliminating unnecessary work. At the start of each feedback session, the instructor summarised the main objectives of the session, pointing out its informal character. The main goals of the feedback session were emphasised as consolidating knowledge and addressing misconceptions, and linking the theory covered in the lectures with the practical aspects of the triaxial test. By that point, students were more familiar with the instructors and their teaching style.

As mentioned previously, in 2016/2017 the triaxial test laboratory sessions took place before the Easter break. Feedback sessions all took place after the Easter break (up to a month after the coursework submission), by which time some students could not remember the experiment or how they had processed the data to produce the report. To overcome this problem, the order of the syllabus and the timing of the laboratory sessions were reviewed and in 2017/2018 some changes were implemented. After the revision of concepts from the first year module geology for engineers, the lectures covered the topic of consolidation. This ensured that all students had received all the lectures and solved problems on the topic before submitting the oedometer test report. The second topic was the shear strength of soils; again, the re-ordering of material enabled all students to attend all relevant lectures and practice solving problems in class and individually before submitting the triaxial test report.

The order of the syllabus, particularly topics 1 to 4 (Section 3.1), from 2017/2018 became:

1. Introduction: revision and application of basic concepts - phase relationships, effective stress.
2. Compression and consolidation: the oedometer test; one-dimensional compression and consolidation; application to field problems.
3. Soil strength and soil behaviour: soil as a frictional material; shear box tests; critical states; peak strengths and dilation; undrained shear strength of clay soils; the triaxial test apparatus; stress parameters; isotropic compression and swelling; shear tests; the Cam Clay model framework.
4. Groundwater, permeability and seepage: Darcy's law and concept of permeability; permeability measurement; flownet sketching, application of flownets.

These changes allowed all laboratory sessions and all face-to-face feedback sessions to take place before the Easter break.

Overall, and despite the issues discussed above, in 2016/2017 the face-to-face feedback sessions seemed to be working well and well received by students. Some of the positive comments collected during the mid-semester course evaluation were very encouraging. For example:

- "the laboratory report feedback session was very helpful – I understand the laboratory fully and feedback was quick and relevant rather than late and unhelpful".
- "what I like best about the module is the quick and comprehensive marking and discussion of laboratory reports."
- "verbal feedback of coursework marking is good to discuss your report and boost understanding."
- "1:2 feedback is excellent, the most useful / personal feedback received at university so far."
- "I thought the face to face marking of the labs was really useful and helpful. I'd like to see that across all modules."

4.2 New improved model

After the improvements implemented in 2017/2018, there have been few if any problems with the process. Students have some lectures on the topics before attending the laboratory session, and all lectures on a topic have been delivered before submission of the laboratory report. Students are encouraged to prepare for the laboratory session by watching the introductory video and reading the laboratory sheets, so they can make the most of the time in the laboratory.

Part of the success is due to the management of student expectations and benefits by the instructors. For example, the face-to-face feedback sessions are explained in detail during the lectures, to avoid any misplaced feeling of pressure. The informality of the sessions is pointed out as an advantage, while students are also encouraged to come and ask questions during the semester. At the start of each face-to-face feedback session, the instructor describes the objectives of the session, highlighting that, more importantly than marking the coursework, the session aims to promote understanding and learning. The informal character of the discussion is pointed out and the students seem content with it.

During the face-to-face feedback sessions, it is possible to identify gaps in knowledge, misconceptions and areas for improvement. Those are discussed with the students, identifying areas for further revision and study. At the end of the face-to-face feedback session the instructor concludes by pointing out the best feature of each report and how it could be improved further. The positive and constructive nature of the feedback seems to be very well received by students. The session usually ends by the student and instructor agreeing an indicative mark, with reference to the published list of objective benchmarks. The instructor explains that marks will be moderated after all the feedback sessions on that report have taken place, and thus may change slightly. For borderline reports, an indicative mark range is agreed.

All comments made during the mid-semester course evaluation being positive (e.g. see Table 1).

Table 1. Some of the students' comments on the feedback sessions

2017/2018	2018/2019
• I like the feedback. • What I like best about the course is the feedback sessions for the laboratory reports. • Carry on with the feedback session for laboratory reports. Is good to see straight away what is right about the coursework and to know whether our understanding is correct. • I like the feedback sessions. • What I like best about the module is the feedback. • Good laboratory feedback that really helps understanding. • Verbal feedback for coursework is amazingly useful. Gives meaning and better understanding of assignments. I feel like I'm learning. • I like the feedback sessions.	• Feedback sessions after the labs are very helpful. • The laboratory report oral feedback sessions are really useful. • The laboratory feedback sessions are extremely helpful. • The feedback sessions two weeks after each laboratory are personal and a good place to ask questions. • I like the laboratory feedback session as individual feedback. • What I like best about the module is the laboratory report feedback. • Carry on with the one to one laboratory feedback session. • Feedback sessions after the labs are very helpful.

4.3 Feedback practice adopted and its link to the literature

The design of the face-to-face feedback sessions addresses many of the fundamental principles of feedback. The mode of feedback promotes assessment *for* (rather than *of*) learning, as it helps define what and when students learn and in identifying gaps in knowledge and areas for further study. The assessment is *aligned*, linking many of the learning objectives of the course, the teaching and learning strategies and the assessment tasks. The reports include tasks and processes that are used in geotechnical engineering and are as authentic as possible. The reports are marked against the published list of benchmark criteria, described in Section 3.3. Interpolation between the narrative benchmark scale points enables reports to be marked to an integer number out of ten (nearest 10%). The indicative mark is set during the feedback session in consultation with the student, with reference to the published list of objective benchmarks. To ensure consistency, the instructors review all reports jointly before finalising the marks. The approach engages students in implementing standards, develops the assessment literacy of instructors, and provides defensibility of professional judgement.

The face-to-face feedback provided to students is *interactive* (a dialogue and an informal discussion), *timely* (provided on day of submission) and *integrated* (summative feedback has a role in enhancing learning). The feedback described herein includes a dialogue and is truly a two-way process. The feedback provided is not a list of what is wrong with the coursework, but a discussion on why some aspects (calculations, interpretations, etc.) are not correct and how the coursework could have been improved, as well as a discussion on the implications of the results for geotechnical engineering practice. The face-to-face feedback sessions were designed to allow for effective feedback, following Hattie and Timperley's (2007) model of feedback, as follows:

FEED UP (Where am I going?): The goals of the assessment are made clear, by making clear the learning intent and criteria for success. These are put forward in lectures at the start of the semester and before the feedback sessions start, as well as at the beginning of each feedback session. In addition, the laboratory sheet and the marking criteria are made available through the e-learning system.

FEED BACK (How am I doing?): During the feedback sessions, students can gauge and are guided into realising how they are doing relative to the intended learning objectives. Students agree on an indicative mark, assigned against the published list of objective benchmarks.

FEED FORWARD (Where to next?): During and after the feedback sessions, if and when students engage in a reflective analysis, they can gauge and are guided into realising which areas of the topic need further or deeper study. At the end of the feedback session, areas for improvement are discussed.

The three purposes of feedback as defined by HEA (2016) are addressed by the face-to-face feedback sessions, and they are all appreciated and recognised by students, as illustrated by the comments included in Sections 4.1 and 4.2. Specifically, the purpose of the feedback is

- ‘orientational’ (“[it] is good to see straight away what is right about the coursework and to know whether our understanding is correct”)
- ‘transformational’ (“verbal feedback for coursework is amazingly useful. Gives meaning and better understanding of assignments. I feel like I’m learning”)
- is effective with an ‘interpersonal’ dimension (“1:2 feedback is excellent, the most useful / personal feedback received at university so far.”).

4.4 Face-to-face feedback and complex concepts in soil mechanics

The soil mechanics course follows the set textbook *Soil Mechanics: Concepts and Applications* (Powrie, 2013). As support materials, students have the book, handouts from the lectures, exercises for application of concepts with different levels of difficulty and complexity and some videos to illustrate simple concepts (such as seepage in soils). Most of these resources are available through the University’s e-learning platform. Some videos are shown in class and referred to when visiting the relevant theoretical concepts; most lectures include time for problem-solving exercises and the students tackle them independently with support from the instructor. All lectures are recorded (video and audio), and students can revisit them when needed. This is particularly useful for students with special learning needs and for international students, as well as for revision.

During the laboratory sessions, students handle soil samples and face the constraints of a real test, rather than simply processing “ideal” test results. This helps students understand the limitations of the tests and how factors such as poor sample preparation can influence results. In linking the test results to field problems, the limitations associated with sampling and defining representative parameters for soils are also discussed. Face-to-face feedback closes the learning loop by clearing up misconceptions, identifying areas for further study and helping students self-regulate their learning needs.

The face-to-face feedback sessions have been particularly useful in reinforcing learning on topics that students tend to find more complex, particularly the two phase nature of saturated soils and the concepts of critical state soil mechanics, including the requirement for and linkages between the three state variables of shear stress, normal effective stress and specific , v (defined as the actual volume occupied by a unit volume of soil solids, $v = 1 + e$, where e is void ratio). In this course, when dealing with one-dimensional compression and consolidation of soils, the response of a soil is expressed as a function of the specific volume of the soil (rather than the void ratio, as often seen in the literature). This links one-dimensional compression to topics on soil strength and soil behaviour, namely isotropic consolidation in a triaxial cell and critical states, all also addressed in the face-to-face feedback sessions.

For the oedometer test report, students use the test results and the quantities derived from the data to estimate settlement and heave for real problems at field scale. Those values and the methodologies used to estimate them are critically discussed during the face-to-face feedback sessions.

In the triaxial test report, students use data from their tests to derive and interpret critical state parameters for the soil. During the face-to-face feedback session, students are guided to link the responses of the specimens tested to the failure mechanisms observed. While some students are able to link the theory to the test results and apply the concepts adequately, others struggle with those tasks and processes. The face-to-face feedback sessions help to clarify the theory and how it relates to the actual data collected. In addition, the dialogue helps to identify areas for further study and some misconceptions. When students act on that feedback they expand their knowledge of the topics and deep learning is promoted. All these processes have helped to promote deep understanding of topics such as critical state soil mechanics, and enabled students to tackle exercises that to some educators seem complex for such a course and level of study.

The face-to-face feedback sessions allowed identification of gaps in knowledge, misconceptions and areas for improvement. The instructors were able to emphasise the importance of exposing students to real data obtained from laboratory tests, rather than the idealised responses often presented in lectures, textbooks and exercises. Although idealised responses are helpful to introduce topics and concepts, students need to be exposed to real data to understand the variability and actual response of real soils.

In the face-to-face feedback sessions on the oedometer test, it became clear that some students had difficulties in scaling laboratory test results up to a field problem, using equations without understanding how to apply them differently in the two situations. The instructors had to point out those differences and explain how the consolidation settlement and the time for 90% of the consolidation to occur are scaled up from the laboratory data to field problems, even though this had been addressed specifically in lectures. Some students also had difficulties in interpreting the initial response of a soil sample during reinstatement of the *in situ* stress state, and the concept of pre-consolidation pressure.

The discussion of the triaxial test report helped clear up several misconceptions. For example, in plotting and determining the Mohr-Coulomb failure envelope for peak strengths, some students had defined an effective cohesion intercept. The lack of physical meaning of this parameter and the curved failure envelope for peak strengths at low stresses were discussed. Conventional plots of shear stress and volumetric strain against axial or shear strain were compared and linked to the state paths on graphs of deviator stress, q, against mean principal effective stress, p′ (the three-dimensional stress invariants), and specific volume, v, against the natural logarithm of p′. The transitory nature of the peak shear strength, its inherent link to dilation and the contrast in both respects with the critical state strength were discussed. For some students, such discussions brought on a lightbulb moment, when concepts suddenly linked and made sense.

4.5 Face-to-face feedback and other feedback modes

The face-to-face feedback sessions have advantages and disadvantages from both the instructors' and the students' perspectives.

For the students, the feedback is quick and timely (on the day of submission) and personalised; the dialogue promotes interaction with the instructors, includes advice for action and promotes opportunities for reflection. As the feedback sessions are timetabled, students are gently compelled to engage with the feedback process. Initially, some students felt that their work was not given sufficient time and attention, while others felt under pressure during the session. Both concerns were successfully addressed through minor changes and explaining the process and expectations to students in advance.

Instructors can mark all reports quickly and the one-to-two contact with the students can be very rewarding, particularly if students truly engage with the learning process. The instructor can use questions to promote critical thinking and development of engineering judgement. In addition, the face-to-face feedback sessions allow students not engaging with the course to be identified and prompted to do better and, when necessary, to seek additional support within the university. Nonetheless, the instructors need to be available for a significant number of hours for the feedback sessions. Some of the comments made and questions answered during the feedback sessions are common to many students, hence some of the feedback is repetitive. However, that is a small price to pay for giving the feedback individually.

The face-to-face feedback sessions are synchronous, interactive and a true dialogue between students and instructor. Communication is two-way and includes verbal and non-verbal communication (gestures, facial expression, body language, tone, etc.). During the sessions, the instructor can adjust the comments and the questions to the students present and their reaction to the conversation. Most students feel valued and supported, both as a person and as a learner. The most common feedback mode in higher education is a set of written comments on the coursework. Such comments take time to produce are often not used by the students. Other modes, such as video and audio feedback, are non-synchronous and provide a one-way communication with the student in most cases a passive receiver.

5 Conclusions

In this paper the implementation of one-to-two feedback sessions in a soil mechanics course has been described and analysed. The opinions and perceptions of students have been presented and the main advantages and disadvantages of this feedback practice discussed, particularly when compared with impersonal, technology-based feedback approaches.

Based on their experience, the authors recommend face-to-face small group feedback in preference to remote technology-based feedback. Such feedback sessions are effective conversations, where students and instructors engage in a productive dialogue. Students feel valued and appreciated, and that they are in fact learning.

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Authors' bios

Margarida Pinho-Lopes, University of Aveiro, Portugal

Dr. Margarida Pinho Lopes is an assistant professor at the University of Aveiro, Portugal, who specialises in the field of geotechnical engineering. She graduated in civil engineering from University of Porto, Portugal, and obtained a M.Sc. and a Ph.D. at the same university. Between 2013-2019 she worked in the UK. Her main technical areas of interest are geotechnical engineering and the application of geosynthetic materials. Her particularly focus is on reinforcement and improvement of soil for a wide range of applications, durability and endurance of geosynthetics, soil-geosynthetic interaction, and constitutive models for geosynthetics. Margarida is involved in research in engineering education, particularly on student-centred learning models (problem- and project-based learning), feedback practices and outreach activities. She is a member of ISSMGE TC306 Geoengineering Education. Margarida has been presented with the New Frontiers of Engineering – Higher Education Teachers award (2012 and 2016) by the Portuguese Institution of Engineers (Ordem dos Engenheiros).

William Powrie, University of Southampton, UK

William Powrie is Professor of Geotechnical Engineering at the University of Southampton, UK, where he served as Dean of the Faculty of Engineering and the Environment 2010-18. His main areas of research are in what have come to be known as Environmental Geotechnics (landfill engineering, waste mechanics and groundwater control) and Transportation Geotechnics, in which he currently holds a major Programme Grant in railway engineering, Track to the Future. He was elected Fellow of the Royal Academy of Engineering in 2009. William is Convenor of the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC), and leads the UK Rail Research and Innovation Network (UKRRIN) Centre of Excellence in Infrastructure. He is Geotechnical Consultant to groundwater specialists WJ Group, and is currently providing specialist geotechnical advice on HS2. He is author of the textbook Soil mechanics: concepts and applications, now in its third edition. He is a previous winner of the British Geotechnical Association Prize (1994) / Medal (2017), the Institution of Civil Engineers Telford Medal (2001) and John Henry Garrood King Medal (2002), and the Institution of Mechanical Engineers Thomas Hawksley Medal (2008).

Potentials for Social Semiotics in Geotechnical Engineering Education

Z. Simpson

University of Johannesburg, Johannesburg, South Africa
zsimpson@uj.ac.za

ABSTRACT: Social semiotics is a branch of linguistics that has been taken up extensively in many fields across the arts, design and humanities. It is concerned with the meaning of signs and symbols within particular social contexts. The principles and methods of social semiotics have begun to be applied within technical fields such as the sciences, medicine and engineering. This paper argues that social semiotics offers potential for application in geotechnical engineering education. The paper identifies three key ways in which social semiotics can be of value in geotechnical engineering education. It does this through a mix of review and synthesis of extant literature, on the one hand, and through presentation of empirical data collected by the author, on the other. The three arguments presented are: 1) that social semiotic approaches offer potential for understanding specific disciplinary values and interests, 2) that it allows for 'unpacking' of disciplinary representations, and 3) that it may offer insight into student's learning and/or misconceptions.

Keywords: social semiotics, geotechnical engineering education, student learning, research methods

1 Introduction

The professional geotechnical engineer relies on skilful deployment of a range of knowledges, practices and skills. Furthermore, the work of the geotechnical engineer involves collaboration with myriad other professionals, such as design, construction and consulting engineers, as well as environmental organisations and clients, who can themselves range from small to medium enterprises to large, state-owned companies. Because of this, geotechnical engineering work is, in part, *semiotic* work: it involves using signs and symbols to communicate with a wide range of audiences and achieve a wide range of tasks. Moreover, it is *social* in that it involves developing shared practices in order to accomplish these tasks. Despite this, little attention has been given to the nature of geotechnical engineering work as social semiotic work. Such attention is important because practicing geotechnical engineers – and geotechnical engineering lecturers – possess tacit knowledge about geotechnical engineering work and its practical accomplishment. However, this tacit knowledge is not evident to geotechnical engineering students – who may benefit from strategies that make this knowledge explicit.

It is the aim of this paper to explore the potential that social semiotic analysis offers geotechnical engineering education for making the tacit aspects of geotechnical engineering explicit. It does this by proposing three distinct but interconnected arguments about the value that social semiotic analysis might offer geotechnical engineering education. The first of these is that social semiotic analysis has the potential to make the interests and values of the profession clearer to students. The second argument is that social semiotic analysis helps to unpack specific disciplinary representations that might otherwise be opaque to students. Finally, the paper argues that social semiotic analysis opens up possibilities for 'seeing' student learning as well as student misconceptions. Each of these arguments is supported by examples collected as part of a previous study into the social semiotic practices of civil engineering study (Simpson, 2015), as well as through review of the extant literature. Of necessity, these examples are quite simple, but are nonetheless representative of the kinds of activities that students are introduced to early on in their studies in geotechnical engineering.

This paper presents an invitation to others to take these ideas forward – both to more complex geotechnical engineering activities and to more concrete strategies for use in the classroom. In order to do so, researchers will need to move beyond 'impact' studies that focus on intervention and measurement. The use of theoretical lenses from the social sciences helps deepen understandings of pedagogy, but requires reading into these theories and careful consideration of how they might be applied in practical teaching and learning contexts. The present paper is a necessary first step in identifying the potential in applying one particular social theory – social semiotics - to deepen our thinking about geotechnical engineering education.

2 Social semiotics and engineering education

Social semiotics is concerned with "meaning in all its appearances, in all social occasions and in all cultural sites" (Kress, 2010: 2). In order to make meaning, we need access to symbolic resources with which we can represent, categorise, configure and comment on our experiences (Ivarsson et al., 2009). Out of the work of Halliday (1978) and others such as de Saussure (1959), the field of social semiotics arose with the aim of exploring how people produce and communicate meaning in specific social contexts (Kress & van Leeuwen, 1996). However, language is only one of the semiotic systems through which meaning-making takes place. As such, *multimodal* social semiotics pays attention to the full range of communicational modes that people use to express meanings, as well as to the relationships between these modes (Jewitt, 2009).

The foundation of semiotic work is the notion of the sign: a symbolic entity that is used as a signifier of a particular meaning, the signified. Within this view, all forms of communication (or representation; or meaning-making) are a process in which a sign-maker has a meaning (or signified) that s/he wants to express and selects the most appropriate sign (or signifier) to represent that meaning, be it an object, concept or entity (Kress & van Leeuwen, 1996). Social semiotics allows investigators to analyse how those signs are used and what their use means, and it is taken as given that different social groups produce different representations of meaning. That is to say, social groups, through their socio-historical development and needs, have fashioned a set of semiotic resources that individuals within that group can use to realise particular intentions and meanings (Kress, 2010). Within this view, learning is a process in which individuals construct knowledge for themselves using "culturally available resources imbued with the meanings of those who have shaped and reshaped them in their social environments, responding to the needs of their times" (Kress, 2010: 14).

The social historicity of signs is important, as it allows researchers to examine the ways in which a specified social group – such as geotechnical engineers – routinely constructs meanings. This has opened up a wealth of research opportunities. For example, social semiotic analyses have been applied to the communication and representational practices of particular groups, ranging from courtroom trial lawyers in both the United States and China (Yuan, 2019), to doctors in a surgical theatre (Bezemer et al., 2011), to Rastafarian herb-sellers in a Cape Town railway-station (Williams, 2017). Social semiotics has also been applied to understanding new forms of communication, such as social media (a recent special issue of the journal Social Semiotics investigates this issue) and memes (Grundlingh, 2018).

Social semiotic analysis has also offered rich potential for investigating educational settings. Again, the breadth of education-related studies undertaken using social semiotics is significant. Such studies range in context from early childhood education (Nichols & Snowden, 2015) to higher education (Ma, 2017), and in discipline from architectural education (Lymer et al., 2011) to language education (Atoofi, 2019), and even physical education (Wright, 1993) and sex education (Liang et al., 2017). Moreover, social semiotic study of educational settings ranges in focus from textbooks (Alayan, 2018; Milaras & McKay, 2019), to teaching methods (Atoofi, 2019), to assessment (Bates, 2018), and to playground interaction (Ranker, 2018), among many other aspects.

While comparatively little social semiotic work has been undertaken in the areas of science and engineering education, a significant and growing body of knowledge in this area nonetheless exists. As early as the 1990s, research attention was given to the value of semiotics in science education (Groisman et al., 1991) and maths education (Vile, 1999). More recently, a selection of papers in the journal Designs for Learning focus on social semiotic approaches to science education (see Airey & Simpson, 2019, for an overview of these papers). Regarding the use of social semiotics in engineering education, specifically, South Africa has seen some attention given to this topic. Initial work in this area was undertaken by Archer (2008; 2009; 2010), and subsequently taken up by Simpson (2013, 2019), Simpson and Archer (2017; 2019), Prince & Simpson (2016) and le Roux & Kloot (in press). However, little work in this area appears to have been done outside of South Africa.

Moreover, a search of the Taylor and Francis online database and EbscoHost's online database using the key terms 'geotechnical engineering' and 'semiotics' yielded only 35 results, of which none were in fact related to the application of semiotic analysis to either geotechnical engineering or geotechnical engineering education. As such, given the occasion of the fifth International Conference on Geotechnical Engineering Education, it is important to consider what this theoretical and methodological approach might offer research in this area. This is particularly important given the value being derived from this approach in other disciplines, including a significant body of research work devoted to the application of social semiotics in maths and science education; see, for example, the work of Lemke (2002; 2004), O'Halloran (2009) and Airey & Eriksson (2019), amongst others. This paper addresses this gap, and proposes three arguments in support of the value of social semiotic analysis in geotechnical engineering education.

3 Social semiotics and disciplinary interest: The first argument

> The physical world is governed by laws whose properties can be captured (in part) by abstract symbolic notation. However, having achieved abstraction, those laws are used to act on the world.
>
> (O'Halloran, 2009: 113)

This quote introduces the core 'interest' of geotechnical engineering: it is a multi-stage, meaning-making process that moves from 'reading the world' (gathering real world data and using this to capture the properties of the physical world in abstract numeric terms) through 'data manipulation' (understanding the data collected and using them to generate designs) to 'changing the world' (using designs to transform the physical environment through construction activities). Johri et al. (2013) refer to this as an inscriptional or representational chain, as depicted in Figure 1. According to them, science moves along this representational chain from left to right (from the world to the word) whereas in engineering movement tends to be in the opposite direction, "as ideas are translated into sketches, formal designs, prototypes, and objects in the material world". However, geotechnical engineering includes elements of both science and engineering design and, as such, incorporates movement in both directions along this inscriptional chain, first from the world to the word and then back into the physical world again. As such, there is "continuous circulation" (Johri et al., 2013: 10) through this representational chain.

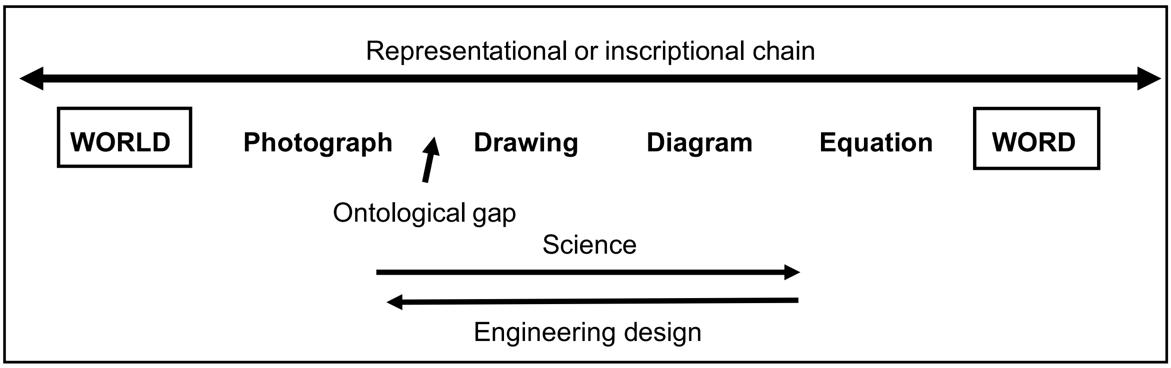

Figure 1. Representational chain in the engineering and natural sciences (adapted from Johri, et al., 2013: 9)

In Figure 1, the elements to the left resemble the physical world. In contrast, representations to the right are more abstract in that they bear no physical resemblance to what they represent. This has the implication that highly abstracted representations are not the entirety of the 'things' they represent; rather, they depict only certain aspects of the real-world phenomenon. A diagram of a truss, for example, represents the forces acting on a structure, but does not say much about the material from which it is made, which is depicted in a photograph or in a naturalistic drawing of a truss. Johri et al. (2013) call this the ontological gap between representations: two different modes of representation capture different aspects of a phenomenon. O'Halloran (2009) recognises this fact in the quote with which this section begins by noting that abstract symbolic notation only partly captures the properties of the physical world. Crucially, however, it captures those properties that are the specific interest of, in our case, the geotechnical engineer.

In multimodal social semiotic terms, the process of transforming meaning from one semiotic form to another has been termed re-semiotisation (Iedema, 2003) or transduction (Kress, 2000a). In this paper, I will use the term transduction. Of course, the notion of transduction does not constitute the entirety of a social semiotic perspective; rather, it is a useful point of departure in that it helps to explain how meaning undergoes shifts as it proceeds along the semiotic narrative of engineering practice, and how these shifts in the representation of meaning point to specific communicative and representational interests. This is possible because different representational modes offer different potential for meaning-making. In other words, some semiotic forms are better for representing specific meanings than others. Indeed, a plethora of representational means have arisen precisely because each is "embedded in distinct ways of conceptualising, thinking and communicating" (Kress, 2000b: 195). As such, the selection of a particular form of representation is never arbitrary; rather, it reflects the particular interests of an individual or group.

This argument is best explained by way of an example, albeit a rather mundane one within geotechnical engineering. One of the fundamental aims of soil mechanics is to classify soils in terms of their properties so as to make judgements as to their suitability for particular construction applications (Verruijt, 2012). As such, the study of soil mechanics is replete with laboratory and field methods for understanding the behaviour and properties of soils. One of the first laboratory tests that geotechnical engineering students are introduced to is sieve analysis, which enables determination of the range of particle sizes that make up a soil sample and, in turn, allows for broad classification of the soil as either a sand (if it is primarily made up of large particles) or as a clay (if it is primarily made up of smaller particles).

The sieve analysis laboratory test is a simple one. A sample of the soil under investigation is taken and passed through progressively finer sieves. These sieves have standard sizes (75mm, 53mm, 37.5mm and so on, down to 0.075mm) and they must be vibrated so as to ensure that only those particles that are larger than the sieve size remain. The sample remaining on each sieve is measured and tabulated. An example of the resultant product is provided in Table 1, which is taken from the results of a sieve analysis undertaken by student-participants in a previous study into the social semiotic practices of civil engineering study (see Simpson, 2015).

Table 1. Tabulated results of a sieve analysis undertaken by student participants

A Sieve Size (mm)	B Mass Retained (g)	C % Retained	D Cum % Retained	E % Passing
9.5	5.5	1.2	1.2	98.8
4.75	68.3	14.3	15.5	84.5
2	143.1	30.0	45.5	54.5
1.18	25.8	5.4	50.9	49.1
0.6	13.6	2.8	53.7	46.3
0.425	8.9	1.9	55.6	44.4
0.3	15.7	3.3	58.9	41.1
0.15	35.9	7.5	66.4	33.6
0.075	17.0	3.6	70	30
Pan	143.6	30.1	100.1	-0.1
Total	477.4			

In Table 1, Column A lists the standard sieve sizes used in the test, ranging from a hole diameter of 9.5mm to one of 0.075mm. Column B indicates the mass retained on each of the sieves. The amount indicated in the 'pan' row is the total weight of those particles that passed through all the sieves and were therefore smaller than the smallest sieve.

Table 1 constitutes a representation of the data gathered through the sieve analysis laboratory work. It is undertaken using the particular coding scheme adopted by the profession for this purpose, namely, a numeric-tabular representation. The selection of a numeric-tabular representation is not arbitrary; it facilitates manipulation of the data obtained according to specific disciplinary interests. This can be seen in the remaining columns. In Column C, the raw numbers obtained in Column B are converted to percentages of the total soil sample. In Column D, those percentages are converted into a cumulative percentage which indicates the total percentage of the soil that is larger than each sieve size. (For example, 58.9% of the sampled soil is larger than 0.3mm in diameter.) Finally, in Column E, this cumulative percentage is inverted so as to give the percentage of the sample that is smaller than each sieve size. (Again, if 58.9% of the sampled soil is larger than 0.3mm, the remainder, 41.1%, is smaller than 0.3mm.)

This example is useful in illustrating how these representational moves, or transductions of meaning, rather than being arbitrary, reflect the particular interest of soil mechanics. In this case, the affordances of the numeric-tabular representation are leveraged so as to manipulate the gathered data (the real world) in order to determine the proportion of soil particles that are smaller than each sieve size. This procedure is standard – and, as already mentioned, rather mundane – practice in soil classification; yet, it nonetheless points to a specific interest in smaller particle sizes. Often, a key interest of soil mechanics is the determination of the proportion of 'fines' (small particles) in a soil sample. This is because such fines can have specific properties that have significant impact on potential construction work undertaken in, on and around them. Put differently, the suitability of soil for construction is sometimes determined by the proportion of fines therein. To this end, the construction of Table 1 results in the observation that 30% of the sampled soil is made of particles that are smaller than 0.075mm in diameter. This is not random, or arbitrary; rather, it is often the specific interest of the geotechnical engineering. This information, along with much more information not discussed here, allows the geotechnical engineer to make determinations as to the suitability of a soil for use in a particular construction project.

This example speaks to the general interest of most work with a scientific heritage: gathering and documenting observations, before producing, organising and reproducing representations of these observations (Juhl & Lindegaard, 2013). More importantly, the semiotic resource utilised – the numeric tabulation – acts to highlight particular information that is tied to the specific interest of, in this case, geotechnical engineering. However, these activities are rendered meaningless to students if the particular disciplinary interest in undertaking them is not made clear, as these practices realise the "social, cultural and historical structures, investments and circumstances" (Iedema, 2003: 50) of geotechnical engineering, in that they are embedded in the broader norms and values of the discipline (Titscher et al., 2000). Thus, the first argument of this paper is that students can be given greater access to the interests and values of the discipline if the ways in which these interests and values are embedded in representational work is made explicit. In so doing, students may experience activities such as the sieve analysis example described here as more meaningful. This pertains to what is *signified* by the representations used in geotechnical engineering. As the following argument will show, the *signifiers* used also require unpacking.

4 Social semiotics and unpacking disciplinary representations: A second argument

Social semiotics is interested in understanding why and how meaning is constructed in particular ways in particular contexts. As shown in the previous argument, this allows for a focus on the particular interest in what is being signified within a particular disciplinary representation. However, social semiotics also offers a lens through which to unpack the highly particular and often highly specialised representations developed within a given field – that is, to unpack the signifiers themselves. For example, recent work in science education by Airey and Eriksson (2019) has shown how social semiotic analysis of the Hertzsprung-Russell Diagram, a central resource in the field of astronomy, can assist in unpacking the peculiarities of this particular representation and, in so doing, overcome potential barriers to students' disciplinary learning.

The same can be done with representations in geotechnical engineering. For example, the data gathered in the previous sieve analysis example is often subsequently re-materialised through a further process of transduction by way of development of a particle size distribution curve, or grading curve. Such a curve is shown in Figure 2. (Note: this figure is an example, and is not the grading curve for the data obtained above; the student participants were not required to draw a grading curve for the data obtained in the above exercise.) As can be seen in Figure 2, the particle size distribution curve is drawn on a semi-logarithmic graph. This means that one of the axes makes use of a logarithmic scale, rather than a natural scale.

This is done because it is not possible to fit the wide range of particle sizes on to a sheet of graph paper using a natural scale in such a way that the graph would be easy to interpret. To explain further: the particle sizes range from 0.075mm (and even lower) to 75mm (and even higher), which represents a thousand-fold variation (and even greater). In a natural scale, the length representing 75mm would therefore have to be a thousand times greater than that representing 0.075mm which would be difficult to achieve within the confines of one page of A4 graph paper, which measures only approximately 300mm in its longest direction. A logarithmic scale, on the other hand, allows certain intervals of space to represent a ten-fold increase in what is being represented. In the example provided, the distance between 1 and 10 (on the x-axis, or horizontal axis), for example, represents such a ten-fold increase. That same distance applied anywhere else along the axis represents not a specific value, but a ten-fold increase in values. Space, herein, represents a proportional increase in value, and not values themselves.

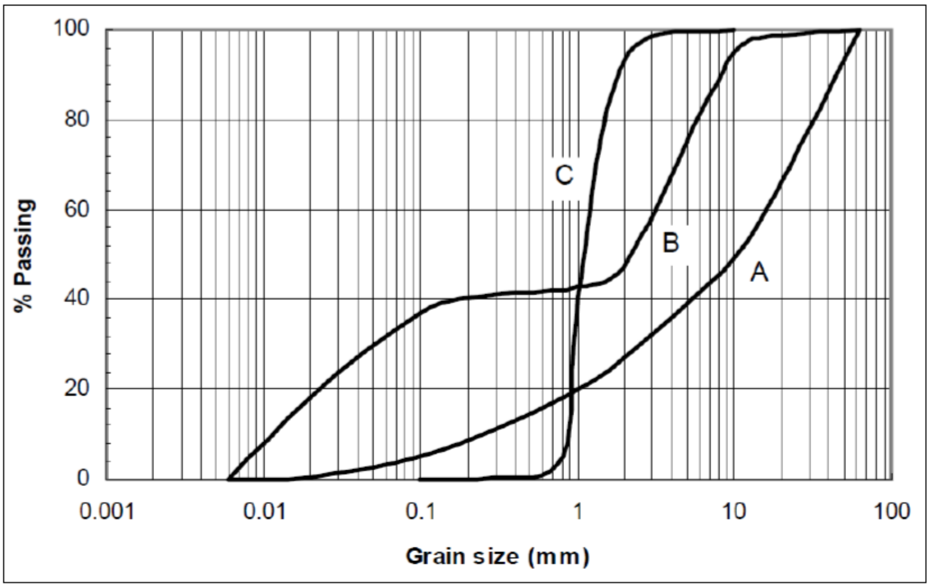

Figure 2. Particle size distribution curves for differently graded soils (Sivakugan, 2000: 3)

In addition, the particle size distribution curve affords the creation of new meanings not possible from the tabulated results. This is made possible by leveraging the particular affordances of a line graph. Whereas numeric tabular representations represent values as discrete, where the intervals between values are not rendered meaningful, line graphs represent data as continuous where the intervals between values consist of innumerable observable and definable values. This allows for the kinds of determinations required to calculate metrics such as the uniformity coefficient, the coefficient of curvature, grading modulus and effective particle size. Thus, the process of transduction not only reflects particular interests but also shifts the meaning potential of the information being represented as different modes offer different potentials and afford different kinds of expression (Kress, 2000a). However, this is only possible if students understand the meaning-making function of the representation being used. In this instance, they need to understand the nature and affordances of a logarithmic graph as well as the differences between discrete and continuous values.

Thus, the second argument of this paper relates to the fact that the representational practices of geotechnical engineering transform concepts and processes into symbolic and visual forms (Nathan et al., 2013). Students require access to these symbolic and visual forms, which relies on classroom strategies that unpack these representations in order to promote understanding on the part of students. In so doing, this paper affirms the finding of Airey and Eriksson (2019) that pedagogy needs to introduce and emphasise the basic features of disciplinary representational resources, and that these features should not, instead, be taken for granted. In the particular example referred to in this section, this may require discussion of the nature of a logarithmic scale, and the difference between discrete and continuous values.

5 Social semiotics and making student understanding visible: A third argument

So far, this paper has argued that the social semiotic question of how meaning is constructed in particular social contexts allows for identification of the particular interest of geotechnical engineers in what is being signified in representations used within the profession, as well as for the need to unpack these representations to assist student understanding. As such, the focus thus far has been on what practitioners do. However, social semiotic analysis can also be applied to the texts that students produce and, in so doing, can be used to make signs of student understanding or misunderstanding visible – an important goal of geotechnical engineering education.

By way of example, let us consider another important property of soils. The way fine particles interact with water is a crucial property of soils (Verruijt, 2012). This is because small particles, or fines, form a plastic-like substance in the presence of water and may expand and contract as water flows into and out of an area with soil that has a high proportion of fine particles. To this end, laboratory tests conducted on soil samples often include determination of the Atterberg limits of a soil. The Atterberg limits determine the water contents at which soils with fine particles lose their solid-like properties and begin to act more like plastic or, ultimately, fluid. One of the most commonly used of the Atterberg limits is the liquid limit (LL), which determines the water content beyond which a soil behaves more like a liquid.

As most geotechnical engineers would know, the Casagrande liquid limit test is undertaken using a device that makes a groove in the sample. The tester turns the handle on the side which causes the device to apply taps to the sample and the number of taps required for the groove to disappear is recorded. The sample is then dried to remove all the water from it. Again, these results are recorded in tabular form. Table 2 is a reproduction of the results obtained by one student-participant as they completed this experiment. As can be seen in Table 2, the test is repeated 6 times, twice each with three different soil-water consistencies. In the table, Row A indicates the number of taps recorded before the groove was closed. Row B indicates the tin number, which is provided only for record-keeping purposes and for ensuring that the samples are not mixed up. Row C indicates the measured weight of each sample, before drying and including the tin in which it is placed. Row D provides the measured weight of each sample, after drying and still including the tin in which it is kept. Row E indicates the measured weight of the tin itself, which would have been obtained before the sample was placed into it. These first five rows therefore record information measured in the course of the laboratory experiment. They are, as was illustrated previously, materialised representations of the information obtained from the laboratory work. They are, in accordance with the terminology previously used, instances of reading the world, and constructing representations thereof that reflect the particular interests of geotechnical engineering as a discipline.

Again, the particular affordances of tabulation are employed so as to manipulate the readings obtained. To this end, Row F indicates the calculated mass of the water in the sample, which is determined by subtracting the mass of the dry sample from that of the wet soil sample. Row G provides the calculated mass of the dry soil by subtracting the mass of the tin from the mass of the dry sample with the tin. Row H presents the moisture content (labelled M.C. by the student-participant) which is determined by calculating the mass of the water (Row F) as a percentage of the mass of the dry soil (Row G). Finally, Row I presents the average moisture content for the two tests done on the soil at each of the three consistencies. As was the case with the sieve analysis, the results of this process are then represented in the form of a line graph, another transduction of meaning. The line graph in Figure 3 was produced by the same student-participant; it represents the number of taps (shown on the horizontal axis) and the calculated average moisture content (shown on the vertical axis), that is, the information from Rows A and I in Table 2.

This example is relevant to the current argument when attention is drawn to the fact that the student concerned obtained an outlying result in the sixth test (a moisture content of 15.75). This outlier is circled with a red, dashed line. The student ought to have repeated the test, given that the result obtained is obviously inaccurate. However, instead, the student chose to ignore the test result and, in Figure 3, took the average moisture content to be 20.22 (the result from the fifth test), simply scratching the sixth test from the record, so to speak.

Table 2. Tabulated results of a liquid limit test

A	No of taps	17	17	28	28	34	34
B	Tin No	33	34	35	36	37	38
C	Tin + Wet Soil	42.04	37.96	32.23	29.34	33.68	38.98
D	Tin + Dry Soil	38.64	35.32	30.66	28.28	31.87	36.82
E	Tin	22.97	23.08	23.08	23.17	22.92	23.11
F	Water	3.4	2.64	1.57	1.06	1.81	2.16
G	Dry Soil	15.67	12.24	7.58	5.11	8.95	13.71
H	M.C.	21.7	21.57	20.71	20.74	20.22	15.75
I	Average M. C.	21.64		20.73		17.99	

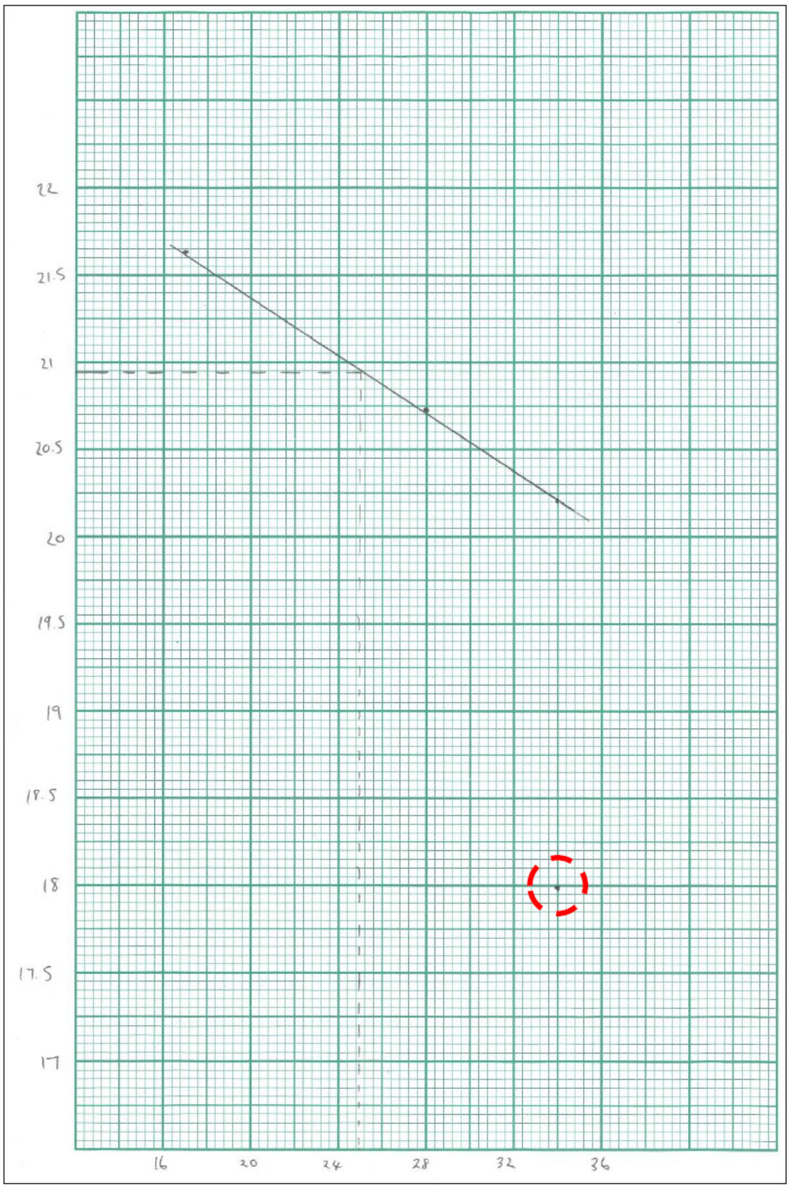

Figure 3. Line graph used by student-participant to determine liquid limit

During a subsequent interview with the student, he indicated that he did this because he knew that the results of the Casagrande procedure should yield a straight line. Although he plotted a point for average moisture content for 34 taps (17.99), he realised that it would be impossible to construct a straight line from the findings obtained. When asked why he did not repeat the test, he indicated that he only realised his results were flawed when he came to draw the line graph, by which time it was too late to repeat the test. It became evident, therefore, that, while undertaking the experiment and tabulation, the student did not understand how the values being recorded were meant to relate to each other. The student, in this example, displayed limited understanding of the purpose of the experiment and of the values obtained and represented in the table, and was only able to assign meaning to the values when representing them in the form of the line graph.

Social semiotic analysis acknowledges that individuals produce texts as per their specific interest in and understanding of that which they represent (Kress, 2000a). As such, when students produce texts that do not meet disciplinary standards and expectations or, more simply, contain errors, these point to a lack of understanding of the subject matter. In this way, social semiotic analyses view ‘mistakes’ as evidence of understanding and misunderstanding. As students are absorbed into a ‘culture’ of representation, the more their representations are socially and culturally shaped (Kress, 2000a), the fewer errors they make, and the more invisible their learning becomes.

6 Conclusions

This paper works from the point of view that geotechnical engineering work is social semiotic work, in that it seeks to represent data gathered from the physical world, either in the laboratory or in the field and to represent this information through processes aimed at transduction of meaning, using the affordances of various representational modes in order to achieve particular aims and interests. The examples provided have all focused on an initial process of ‘reading the world’: this process gathers data about the physical world which then becomes input for subsequent practices aimed at manipulating these data, which in turn become input for further practices aimed at effecting changes in the natural and/or built environment. Such social semiotic analysis of geotechnical engineering education offers unique insight into the practices that underpin the discipline and, in so doing, offers significant potential for improving pedagogy.

However, this paper has not extended the analysis to design and construction (those processes aimed at moving back into and effecting change in the world). Moreover, the paper has considered rather simple examples of geotechnical engineering, albeit that the examples selected are quite typical of initial activities that might be undertaken as students begin their studies in geotechnical engineering. Finally, this paper has not attempted to develop concrete strategies that can be deployed in the geotechnical engineering classroom. Instead, this paper should be read as an invitation to geotechnical engineering educators to consider the potential of the social semiotic approach presented herein and take the ideas forward by applying it to more complex activities, and to a range of classrooms.

Geotechnical engineering education researchers should make attempts to imbue their analyses and findings with theoretical – as well as methodological – rigour. Social lenses, such as that provided by social semiotics, may offer geotechnical engineering education scholarship robust vocabularies for talking about teaching and learning that may, in turn, elevate their analyses and findings above mere anecdote or intervention. They may offer depth of understanding of the causal factors that hinder student understanding.

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Author's bio

Zach Simpson, University of Johannesburg, South Africa

Dr. Zach Simpson is a Senior Lecturer in the Faculty of Engineering and the Built Environment at the University of Johannesburg in South Africa. He holds a PhD in Education from the University of Cape Town in South Africa, specialising in engineering education. His research focus areas are engineering education, higher education studies, multimodal social semiotics and academic literacies. His work is largely concerned with how students come to understand and use the meaning-making practices of engineering. He has been a member of the South African Society for Engineering Education since 2011, and is editor-in-chief of the journal SOTL in the South.

Lessons Learned about Engineering Reasoning through Project-Based Learning: An Ongoing Action Research Investigation

Z. Simpson & M. Ferentinou

University of Johannesburg, Johannesburg, South Africa
zsimpson@uj.ac.za, mferentinou@uj.ac.za

ABSTRACT: In this paper, we report on the third cycle of an ongoing action research project, the purpose of which is to develop engineering students' skills regarding judgement and reasoning. Students were required to develop a solution to an open-ended problem, and perform a series of analyses in order to propose a safe and viable solution to the given problem. The results of the study suggest that the students found it challenging to handle such an open-ended design problem, and required greater guidance on the part of the lecturer.

Keywords: Action research, student engagement, teaching methods, education research methods

1 Introduction

Geotechnical engineering requires extensive reasoning, judgement and evaluation, which rests on a dual base of technical knowledge and experience. Traditionally, geotechnical engineering curricula at universities have focused on the development of the first base, namely technical knowledge. More recently, however, there has been increasing focus on introducing students to the kinds of practices (particularly in terms of reasoning and judgement) that are required from geotechnical engineering professionals.

This paper presents the results of a third cycle of action research aimed at developing civil engineering students' engagement with geotechnical engineering. In particular, it aims to investigate the extent to which a geotechnical engineering design project allowed students to develop the kinds of reasoning, evaluation and judgement processes required in geotechnical engineering practice. The paper begins with a review of the literature pertaining to the development of engineering reasoning and judgement, both at university and in practice, prior to providing a description of the methods deployed in this study. Thereafter, the results obtained are discussed and conclusions drawn.

2 Engineering judgment and reasoning: In practice and in education

The importance of engineering judgement and reasoning is made clear in empirical research as well as in the prescribed outcomes required of engineering programmes in countries aligned with the Washington Accord (IEA, 2019). For example, in the United States, engineering graduates are required to "use engineering judgment to draw conclusions" [Accreditation Board for Engineering and Technology (ABET), 2018] and, in South Africa, they are required to "exercise judgment and take responsibility within own limits of competence" (Engineering Council of South Africa, 2019: 14). Empirical research further reinforces this need. A study undertaken at Massachusetts Institute of Technology (MIT, cited in Crawley et al., 2007: 66-69) found that engineering reasoning was rated as the most important skill required of engineering graduates amongst all groups of participants, including faculty, industry, recent alumni and experienced alumni. This MIT study was replicated in Sweden, and similar findings were obtained.

As such, though the importance of engineering judgement and reasoning is relatively clear, the definition of these terms is somewhat less clear. A search of EBSCOhost Research Platform (EBSCO, 2019) using the Boolean phrase [(judgment OR reasoning OR judgement) AND "geotechnical engineering"] yielded 40 search results. Of these, four articles could be excluded as they did not actually deal with geotechnical engineering-related topics or, in one instance, it was a brief editor's note about another of the articles in the search results. Of the remaining 36 articles, three (O'Kelly et al., 2009; Pierce et al., 2013; Bourne and Baxter, 2014) dealt with engineering education, albeit one of them (O'Kelly et al., 2009) was a brief piece about the history of the geotechnical engineering programme at Trinity College Dublin, which was thus excluded from further analysis. Another four (Christian, 2004; Bea, 2006; Marr, 2006; Muszynski, 2009) dealt with the topic of engineering judgement in geotechnical engineering in a meta-reflective manner. The remaining 29 articles were technical works that mentioned engineering judgement or reasoning in their abstracts, but were not specifically about engineering judgment.

In the six articles that explored engineering judgement and reasoning, either in geotechnical engineering education or practice, perhaps the strongest rationale for its importance is that provided by Christian (2004: 1001):

> "It is clear that our knowledge of the geological and environmental factors affecting geotechnical engineering is imperfect and that it will remain so. Although modern developments in remote sensing and information technology promise to ameliorate this situation, we are not likely ever to have as much or as reliable information as we would like to have. However, we have to proceed with our projects. The first step is to recognize the extent of our ignorance and to understand whence it arises. We can reduce uncertainty by obtaining more information, especially when the search for more information is guided by a rational understanding of the nature of uncertainty and its impact on our decisions. "

Given the importance placed on engineering judgment and reasoning in engineering practice, considerable attention has been given to these topics in the engineering education literature. All of the major engineering education journals include multiple articles that reference this point. These studies have been undertaken, inter alia, in the context of project-based learning (Jaeger & Adair, 2015), engineering ethics (Harding et al., 2012; Berdanier et al., 2018; Hess et al., 2019), conceptual understanding and reasoning (Van Meter et al., 2016; Brown et al., 2018; Goncher & Boles, 2019), assessment (Leite et al., 2011; El-Maaddawy, 2017) and engineering design (Campbell et al., 2019; Dasgupta, 2019).

One way of developing engineering judgement and reasoning on the part of university students is through implementing problem-based learning (PBL). PBL is an approach to teaching and learning that focuses primarily on the learning process, that is, on *how* students should learn rather than what they should learn. De Graaff & Kolmos (2003; 2007) suggest that problem-based learning begins with analysis of problems, which can range from open-ended to well-defined. Generally, PBL also involves team-based learning, in which learning, as a social act, takes place through dialogue and communication with peers (de Graaff & Kolmos, 2003; 2007).

3 Methodology

The present paper reports on the results of the third cycle of an ongoing action research project. Action research is an iterative approach to research characterised by consecutive cycles of planning, implementation and reflection with respect to an identified problem (Christie & de Graaff, 2017; Bevins et al., 2011). This is depicted in Figure 1. Action research is widely used in educational research albeit less so in engineering education research. Nonetheless, Christie and de Graaff (2017) argue that action research is "a suitable research model for engineering educators who wish to do research on active learning in engineering education".

In this ongoing action research project, the initial problem identified was lack of engagement on the part of students within a geotechnical engineering course. This course forms part of a general degree in civil engineering, and is the second of three consecutive semester courses that the students undertake on geotechnical engineering.

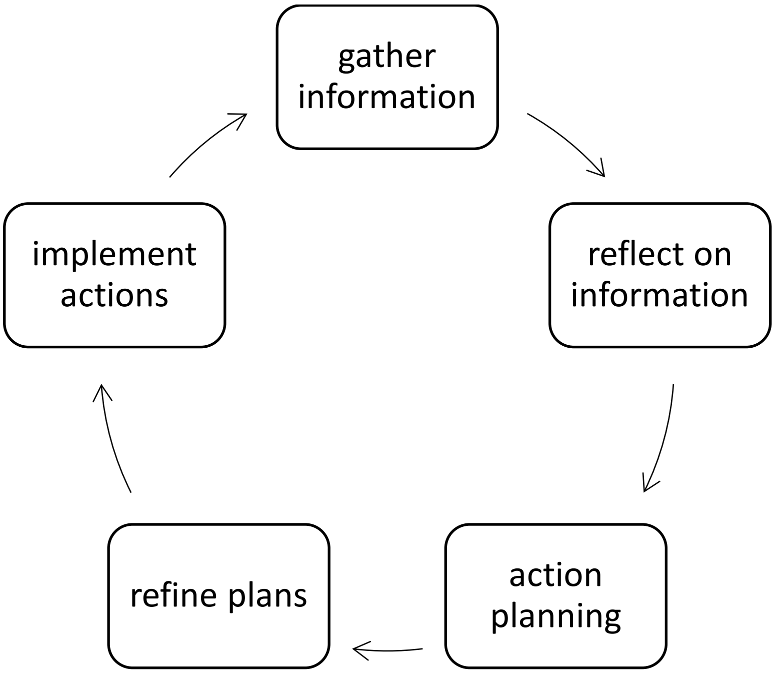

Figure 1: The action research cycle (adapted from Bevins et al., 2011: 404)

3.1 First cycle

In the first cycle of the research, conducted in 2017 (see Ferentinou & Simpson, 2019a), a number of changes in the module were implemented, such as the introduction of a guest lecture by an industry professional, greater interaction during class activities, weekly quizzes and increased use of software applications such as Slide 2018 within the classroom.

3.2 Second cycle

Despite the fact that the first cycle yielded greater student satisfaction with the course – and improved engagement with the course material as a result – it was observed that students continued to struggle to link the course materials and activities to the demands of geotechnical engineering practice. This necessitated a second cycle of research, which aimed to link student learning to engineering practice through project-based learning. As part of a second cycle, conducted in 2018 and described in Ferentinou & Simpson (2019b), students were tasked with a design project that required them to offer geotechnical engineering solutions for a commercial development founded on problematic geotechnical conditions. Although the design project was, in large part, successful, the researchers nonetheless identified a need to unpack the students' engagement with the project to examine the kinds of reasoning, evaluation and judgement practices developed through participation in these activities. This is the focus of the present paper.

3.3 Third cycle

In the current cycle, students were again required to undertake a design project. The lecturer (the second author of this paper), in an attempt to simulate real-world practice, acted as the project manager on the students' projects, which were conducted in groups of four students. The lecturer met with each group individually four times during the semester. In preparation for these meetings, the student groups were required to submit questions or preliminary designs for discussion. The project culminated in the submission of a report and delivery of a presentation, both aimed at proposing a safe and viable design solution and explaining the reasoning behind the proposed design. Moreover, the design needed to be in accordance with relevant standards as well as include consideration of financial viability, the environment, and questions of sustainability. The presentations delivered by the students were co-assessed by an industry professional, who also provided the case study on which the project was based. The aim of these decisions was to develop the course as an integrated learning experience, where students simultaneously develop disciplinary knowledge and professional engineering skills (Crawley et al., 2007).

In order to evaluate the success of the designed intervention, three types of data were collected. First, the group meetings held with each group were observed (by the first author of this paper) and the questions and preliminary designs submitted by the groups were collected and analysed. The focus of this analysis was on categorising the questions submitted in terms of focus, as well as on categorising the groups' proposed design solutions and identifying misconceptions in the students' design proposals. These questions – and observation of the meetings – were used to understand the student-participants' process regarding developing a design solution (these data are discussed in Section 3.1). Second, the students' final presentations were observed and their final technical design reports collected. In this regard, the focus of the analysis was on classifying the groups' design solutions and identifying the strategies used to display their reasoning and judgement (these data are discussed in Section 3.2). Finally, in order to validate the findings obtained, the industry-based co-assessor was also asked to produce written commentary on the work produced by the student groups (these data are discussed in Section 3.3). The focus of this input was on the quality of the reasoning and judgement displayed by the students during the presentations, and how this accorded with the kinds of reasoning and judgement demanded in geotechnical engineering practice. The intention of gathering this input was to support, or deepen, the observations and findings obtained from the first two sets of data.

3.4 Ethical considerations

All students – as well as the industry participant – gave informed consent to participate in the present study. All participants were given the option of not participating and had the right to withdraw from the research at any time. Their privacy and confidentiality were guaranteed and have been preserved in the present paper.

4 Student engagement in project-based learning

4.1 Focus on process

The problem given to the students introduced a typical road embankment that showed signs of pavement cracking and severe erosion, indicating the possibility of a slip failure. The causal factors identified by the lecturer were a lack of maintenance of the storm water drainage system and poor fill material. In addition to this, water was seeping under the embankment from a pond in which storm water was collected. The critical parameters were given as part of the problem definition. The students were required to present a design solution that would protect the slope from further erosion and ultimate failure. As part of their analysis, the students needed to perform (a) a deterministic analysis under Ultimate Limit State condition, (b) a probabilistic analysis, (c) a Serviceability Limit State analysis to evaluate long term settlement of the embankment, and also (d) consider practicalities, such as revegetation of the slope, drainage (or storm water system), and environmental aspects. As already mentioned, students had to submit a final report and make a 10-minute oral presentation

For their analysis, students could use Slide 2018 (RocScience, 2018). The students were introduced to the software during the course and were able to ask the course tutor for assistance during scheduled tutorials and practicals. In addition, probabilistic analysis is not a stated outcome of the course and students were expected to self-study this. This was required in order to ascertain their ability to solve problems without having all the required information easily available. Admittedly, therefore, the expectations of this course were particularly high, aimed at the level of a "capstone" design course, rather than a third year module. However, the researchers felt that students might benefit from being introduced to project-based learning earlier so as to be more adequately prepared for the capstone design course they were to face the following year.

The site conditions and relevant contextual information were provided as part of the design brief, which was prepared by the lecturer in consultation with the industry representative. The design brief was intentionally open-ended so that students were able to explore any solutions they deemed suitable. The project took place over an entire semester, during which time the students had four formally-scheduled opportunities to meet with the lecturer, who acted as project manager, as already mentioned. To this end, the students were able to ask questions and present ideas – but the lecturer intentionally avoided providing direction for the groups' individual designs, a decision that, in retrospect, was problematic, as the students required more direction than was initially assumed.

4.1.1 Findings from initial meetings

There were definite shifts in the students' thinking over the course of the meetings with the lecturer. During their initial meeting, held early in the semester, the student groups largely focused on site conditions and contextual information. Initially, the observational data collected – as well as analysis of the actual questions posed by the students – revealed four key themes. These pertained to i) misidentification of the central design problem, ii) difficulties understanding the geometry of the design problem, iii) cost and environmental considerations, and iv) the need for assumptions. Each of these themes is explored, in turn, in the paragraphs that follow.

Many of the questions asked by the student groups reflected a misidentification of the central problem underpinning the design solution. For example, many students asked for rainfall data, which reflected a misunderstanding of the seepage problem – which was due to the presence of a pond, rather than excessive precipitation. Moreover, the embankment that failed was constructed in order to carry a road, and many groups asked about the bearing capacity of the road and the materials used in the design of the road pavement. Again, this reflected a misidentification of the core problem – in that the road had not failed, but the embankment on which the road was constructed; the road was not the cause of the slope failure.

The students' misidentification of the problem at hand, in many instances, seemed to emerge from difficulties understanding the geometry of the problem. Many groups did not understand where the pond was located in relation to the embankment – and, despite the fact that an image of the failed slope was provided, many students did not understand the geometry of the slope itself, misrecognising the slope height, angle, road placement and so on. This led to some unworkable initial design solutions, such as construction of a bridge (this assumed that the road was crossing a ravine, which was not the case as the road was running parallel with the ravine – hence the embankment).

Another significant point in the students' initial ideas and questions related to consideration of economic and environmental factors. Several groups proposed bringing in entirely different materials and removing the in-situ material, which displayed a lack of consideration of the costs of such a solution, and ignored the fact that techniques exist to improve material parameters, such as geomaterials and the like. In addition, some groups asked about the local fauna and flora, both in terms of its role in causing the failure, but also in terms of the importance of considering this in the design solution.

Finally, several groups requested information that was unavailable or that needed to be assumed. In these cases, the groups were expected to make assumptions based on the information that was available, and to make these assumptions explicit in their design solution. For example, the exact dimensions and location of the pond were not given, and students were expected to make assumptions in this regard, possibly through developing a range of scenarios. Some groups also wanted more direction than the lecturer was willing to give. For example, some groups asked what factor of safety was to be achieved and others asked if they were expected to use geosynthetics in their solution. In these instances, students were advised to rely on their own judgment as well as on relevant standards, rather than relying on being told how to approach the design problem. Students had access to a number of relevant standards – and the purpose of the project was to expose them to problems in which the necessary information was not made explicit. Rather, they were expected to determine what information they would need and how to obtain it.

Overall, therefore, the initial project meetings with the various student groups revealed that very few groups were immediately able to identify the central design problem, with many student-groups initially focusing their effort on pavement design, geometric design of the road itself, or design of an altogether new slope – rather than rehabilitating the existing slope by addressing the seepage problem prevalent.

4.1.2 Findings from the final meetings

Fortunately, by the final group meetings, all the groups were able to propose a design solution that addressed the core problem of slope failure (but not always the underlying cause of the slope failure: seepage), albeit some groups continued to misunderstand the geometry of the slope. Analysis of the final meeting sessions yielded seven key themes: i) continued misidentification of the root cause of the design problem, ii) technical misconceptions pertaining to the critical slip surface, iii) inadequate attention given to boundary conditions, iv) continued lack of consideration of cost, v) lack of consideration given to constructability, vi) lack of consideration given to land use, and vii) frustration on the part of students with a perceived lack of guidance provided by the lecturer.

The first theme emerged from the fact that while most groups addressed the problem of slope stability, relatively few offered a solution to the seepage problem caused by the presence of the pond above the slope – which was the root cause of the slope failure. Moreover, many groups focused on one dimension (erosion, global stability, seepage) rather than all of these elements of the problem.

Themes (ii) and (iii) are primarily technical in nature. In the first instance, few groups were able to see the link between the critical slip surface and the need for soil reinforcement. Most of the groups included soil reinforcement in their proposed design, but only one or two groups (out of almost 25) extended this reinforcement (whether in the form of soil nails, geotextiles and the like) through the critical slip surface, thus doing little to enhance the tensile strength along this surface and failing to secure the global stability of the slope. In the second instance, many groups failed to accurately set the boundary conditions for their design models, which were produced on Slide 2018 (RocScience, 2018). This meant that groups' modelling of the seepage flow was often inaccurate and unreliable although the students had been given explicit instruction regarding the importance of setting correct boundary conditions.

The next three themes pertained to factors that students were required to give attention to in reaching design decisions. The first of these factors was cost. To this end, most of the student groups provided solutions that demonstrated significant over-design (though still failing to obtain adequate safety factors because of the aforementioned challenge with regard to the critical slip surface). The students also demonstrated a lack of consideration of constructability. For example, many groups proposed a solution involving placement of geomaterials to reinforce the embankment. However, many of these groups placed these geomaterials perpendicular to the slope surface, rather than horizontally – which would create significant challenges for construction and placement. Another problematic – but common – design proposal was to reduce the slope angle. This widens the amount of land needed which does not consider the extent to which this is possible, given questions of availability of land, as well as ownership of the land adjacent to the existing embankment. Moreover, it also increases costs due to the need for more materials. Finally, many groups reduced the slope angle, but still added reinforcement, which displayed a lack of understanding of the goal of the use of reinforcement: namely, to achieve steeper, more economical, slope angles.

Finally, what was also noticeable throughout the meetings with the groups was the fact that some students expressed a degree of frustration with the open-ended nature of the design problem. In one instance, some students became visibly upset at the lack of explicit guidance provided by the lecturer. For example, this group asked if vegetation would be sufficient to prevent erosion at the toe of the slope (also part of the initial design problem) and were irritated when the lecturer responded by suggesting that they need to decide for themselves if vegetation would be an appropriate solution and then justify their decision.

Overall, therefore, by the final project group meetings, most groups had developed an initial design solution, but they generally arrived at these solutions through trial and error using the software that was available (in their final presentations, many groups admitted to this fact). Very few of the groups were able to clearly articulate the assumptions they made and justify these assumptions, or to justify the design decisions they had made. Moreover, the groups struggled to balance the need to make assumptions based on incomplete information, while still paying attention to the competing demands of safety, cost, constructability and environmental impact. Unfortunately, many of these challenges persisted into the students' final project reports and presentations.

4.2 Focus on final product

Based on our analysis of the submitted reports, it was revealed that the students: i) reviewed the problem, which was open ended, ii) tried to clarify the meaning of terms, the geometry and the parameters that controlled the stability of the given embankment, and iii) analysed and defined the problem, with guidance from the lecturer.

All the groups managed to retrieve and organise pre-existing knowledge (for example, seepage analysis had been taught in the previous semester and was required in order to solve the problem). They also identified the knowledge (reinforcement, erosion protection) required. However very few groups attempted to design a drainage system, in order to control seepage.

The presentations were on time, and well prepared; however, the content contained several deficiencies that were also present in the reports submitted. Through this process, students developed professional engineering skills such as oral communication and collaborative work. As such, the learning objectives were partially met. However, the safety factor that was calculated by the majority of the groups was lower than what is expected in the relevant standards, to which the students had access. In many instances, seepage analysis was not performed correctly, as the boundary conditions of the problem were wrong for almost 50% of the projects.

Many reports focused primarily on problem definition, background and literature review, rather than methodology, analysis and presenting a solution. The editorial standard of the majority of the reports was not very high.

The concept of probabilistic analysis was not examined at all in a majority of the reports. Where it was included, it was not supported by sufficient support, explanation or reasoning. Limit state design and serviceability based design was not discussed by any of the groups, although the students had received instruction on these during the course of the semester, albeit in the context of retaining walls.

4.3 Industry perceptions of students reasoning, judgment and evaluation practices

The industry guest examiner felt that the lecturer needed to be stricter with the students regarding deadlines as this would demonstrate that students are able to manage their time, which is an important skill. The external examiner also identified problems in the students' identification of the failure mechanism, which suggested a lack of understanding of the basics of geotechnical design (i.e. loading and drainage calculations and criterion for acceptance) on the part of the students. While some groups understood this and correctly applied these using appropriate software, most of the groups simply targeted a safety factor without understanding the principles underlying the safety factor. Likewise, although it was required to perform deterministic, limit state (Ultimate Limit State and Serviceability Limit State) and probabilistic analyses, these were not all performed. When probabilistic analysis was performed, it was not accompanied by any reasoning; instead, the function was simply automated using the software, without trying to understand the underlying theory or purpose. Order of scale was also problematic on the part of the students. For example, the flow rates that were calculated during the seepage analysis were unrealistic and safety factors of 1.1 were considered adequate. This again suggests that students did not exercise judgement and reasoning regarding the results they obtained. Finally, regarding the use of geosynthetic materials, students demonstrated that they understood that geosynthetics provide tensile properties, albeit the parameters students used were not justified – and could not be explained (even when correct).

4.4 Reflections

Marr (2006: 98) argues that: "Judgment is critical thinking and reasoning. Judgment is arriving at a sound conclusion despite having had to sift through masses of conflicting, contradictory, erroneous, irrelevant information." Based on this definition, the majority of the students presented limited to low reasoning. Based on the outcomes of this third cycle of action research, there is a need to develop strategies to assist the learners with more guidance and scaffolding. One form of guidance could be worked examples, in order to provide the students with problem solving models (Chi et al., 1982). It might be more beneficial to teach the steps of problem solving, from visualisation to solution evaluation.

5 Conclusion

In this study, the authors sought to demonstrate that open-ended, problem-based learning activities could develop within students the kind of engineering judgement and reasoning practices required in geotechnical engineering practice. However, it was found that the students were quite resistant to the open-ended nature of this task, and they found it difficult to attend to all the competing requirements of this project. In retrospect, the researchers needed to do more to balance the need to encourage students to think, act and learn independently, with the need to provide explicit instruction, guidance and scaffolding. We had thought that the students would be in a position to work independently; however, it appears that Taber's (2010: 33) argument "that minimal guidance, almost letting the learners just get on with it, is seldom an appropriate educational strategy" holds true. This research, despite not achieving its original aim, demonstrates the challenge that students experience in moving from acquiring fundamental geotechnical engineering knowledge to applying this knowledge in more complicated real-life engineering design projects. If students are to acquire engineering judgement and reasoning skills, there needs to be more continuous formative feedback than was provided in the delivery of the module in its present form.

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Authors' bios

Zach Simpson, University of Johannesburg, South Africa

Dr. Zach Simpson is a Senior Lecturer in the Faculty of Engineering and the Built Environment at the University of Johannesburg in South Africa. He holds a PhD in Education from the University of Cape Town in South Africa, specialising in engineering education. His research focus areas are engineering education, higher education studies, multimodal social semiotics and academic literacies. His work is largely concerned with how students come to understand and use the meaning-making practices of engineering. He has been a member of the South African Society for Engineering Education since 2011, and is editor-in-chief of the journal SOTL in the South.

Maria Ferentinou, University of Johannesburg, South Africa

Dr. Maria Ferentinou is an Associate Professor at the University of Johannesburg in the field of Geotechnics – Engineering Geology. She holds a BSc degree from the University of Patras, and a PhD from the National Technical University of Athens. Her main research focus lies on slope stability assessment, study of rock engineering systems, and application of artificial intelligence in geotechnics. Currently she is engaged into slope monitoring and sinkhole propagation monitoring using fiber bragg gratings and small scale physical models. Her profound love for teaching has evolved in developing a research interest towards engineering education, and pedagogical strategies aimed at better preparing engineering students. She has been a member of the South African Society for Engineering Education since 2017.

Priority Theme 2: Incentives and Opportunities for Industry-Academia Collaboration

The Role of International Exchange Visits in the Geotechnical Education of Undergraduate Students

V. E. Dimitriadi[1] & K. G. Kliesch[2]

[1]*Edinburgh Napier University, Scotland, UK*
V.Dimitriadi@napier.ac.uk

[2]*Frankfurt University of Applied Sciences, Frankfurt, Germany*
Kurt.Kliesch@fb1.fra-uas.de

ABSTRACT: The increasing international presence of design and construction companies has generated the need for civil engineering graduates to be able to work in an international environment, understand a series of international design standards and - with respect to geotechnical engineering - deal with different types of soil conditions. The above trend has placed an emphasis on internationalising civil engineering degrees, which in turn generates a challenge to educational institutions in terms of curriculum design. In the present paper, the authors take inspiration from the student exchange programme of International Project Week (IPW), an initiative that brings together students from seven (7) different European Institutions for a week of lectures, site visits and a final group project. The authors provide a comprehensive description of the programme and attempt to explore ways that this and similar events can shape and contribute to the geotechnical education of their respective institutions. The ultimate objective is to trace potential margins for improving the existing undergraduate geotechnical curricula and propose modern pedagogical means for their enrichment.

Keywords: geotechnical education, pedagogical research, curriculum design, internationalisation

1 Introduction

The globalisation of the economy has had a direct effect upon the strategic planning of many companies and organisations, which focus on emerging economies. The need for new infrastructure and buildings in developing countries has led many design and (mostly) construction companies to grow beyond their national markets. This shift in development focus has altered the workforce trends and the desired professional qualifications of engineers, hence creating a shortage of skilled professionals (Mariasingam et al., 2007). Darwish et al. (2012) make a very thorough analysis of the impact of globalisation upon the construction engineering education and among others highlight some of the technical and social skills that new graduates need to have in the construction industry (technical competence, multicultural communications skills, etc.). Regarding geotechnical engineering education, globalisation of the profession poses an extra layer of complexity, as young graduates not only need to possess sufficient technical skills and a good understanding of the international design codes and standards but need to be able to deal with very different soil conditions. Hence, in this internationalised context current geotechnical engineering programmes face a significant challenge; that of providing their students with a global perspective.

The present paper addresses the question of how exchange visits among European institutions can contribute to the internationalisation of geotechnical education, with a view of preparing undergraduate students to respond to future professional challenges. More specifically, the student exchange programme entitled ‘International Project Week’ (IPW) is used as the starting point to explore how such events can shape and contribute to the geotechnical education. The International Project Week programme is designed to bring together students from the 7 participating European institutions

[Edinburgh Napier University (ENU), Amsterdam University of Applied Sciences (Hogeschool van Amsterdam), Technical University of Denmark, Frankfurt University of Applied Sciences, University Claude Bernard Lyon 1, University of Life Science and Technologies (Latvia), Roma Tre University] for a week of guest lectures, site visits and a final group project. The principal aim of IPW is to promote collaboration among students of different nationalities during the event, but more importantly to assist students understand the international aspect of their future profession. Additionally, the programme helps the participating universities adopt an 'extrovert' approach of teaching in engineering and initiate opportunities for students and staff members for teaching and/or research exchange visits between institutions.

The IPW concept was first established by Peter de Klerk from Hogeschool van Amsterdam, as a voluntary partnership among European educational institutions. His vision was to provide engineering students in Europe with opportunities for knowledge exchange and networking. The first IPW event took place in 2007 in Amsterdam, with 4 member universities, and approximately 120 students (Taylor et al., 2009). Since then, the network of participating institutions has expanded to seven (7) and the structure of the programme has been standardised to include guest lectures from either academia members or industry representatives, site visits of different civil engineering projects, social events and group work in mixed international student groups. The event is taking place yearly, in April or May, and the location changes between the member institutions each year. The latter is decided at the IPW event of the previous year, where it is further confirmed that all participating institutions are willing to continue. The number of participating institutions is subject to practical restrictions, such as number limitations for site visits. Historically, the number of participating students ranges between 150 – 200, which creates the main challenge with reference to finding and organising site visits. Requests from new institutions to join the programme are discussed and decided among the existing IPW members. The participating students normally cover their own travel and accommodation costs, while the hosting institution covers all other costs (lunches, promotional material, minor transportation costs, etc.) along with any support obtained from industrial partnerships.

Within the above context, the focus of this paper is upon the IPW events organised by Edinburgh Napier University in 2019 (6^{th} – 9^{th} of May) and Frankfurt University of Applied Sciences in 2016 (9^{th} – 12^{th} of May). In the first section of the paper, a more detailed description of the programme's layout is given, attempting to highlight its pedagogical dimension. In the sequel, key information about selected site visits with a geotechnical interest, which were organised in the two cities, are collected and presented (Queensferry Crossing in Edinburgh and the Schiersteiner Bridge in Frankfurt). The main geotechnical design issues are identified, in view of tracing potential margins to improve existing undergraduate geotechnical curricula and propose modern pedagogical means for their enhancement.

2 Structure and Workflow of IPW

2.1 Structural Frame

The IPW week typically starts with the registration of the participants, welcome speeches from the Dean and the organisers and continues with the invited lectures. The topic of the invited lectures is mainly related to the site visits of the following days, but it can also be linked to the main research area of the hosting institution or even have a broader civil engineering content. The second and third days are dedicated to the site visits and typically, at the end of the third day a social gathering is organised by the students of the hosting university for their student guests. This can be an evening at a local pub or dance club. A dinner is also organised for the members of staff, which helps share their experiences on the past days. The fourth day is dedicated to the main student activity, which normally has an open topic each year, a staff meeting, and the closing ceremony. Students and staff are gathered at a common hall for the closing ceremony where winners of the student activity are selected, small prizes are handed out and short talks by the organisation committee are delivered.

In the 2019 IPW event in Edinburgh, four invited lectures were scheduled. Two of them were relevant to the site visits (New Waverley development and the Forth Road Bridge) and were delivered by engineers who were currently working or have worked on the projects. The third one covered the similarities and differences in the geotechnical conditions between Edinburgh and Glasgow and was delivered by a local senior geotechnical engineer. The fourth lecture was about building sustainability, which is a very active research area at Edinburgh Napier University and was delivered by an Associate

Lecturer of ENU. The site visits of the following two days are briefly presented in Table 1. Regarding the 2016 IPW event, held in Frankfurt, the site visits are summarised in Table 2, whereas the guest lectures covered the Frankfurt Public Transport System, the Skyscrapers and the European Quarter.

Table 1. Brief description of the site visits during the 2019 IPW week

Site visit	Brief description
The New Waverley development	A tour of the redevelopment of a 425,000 ft^2 area comprising offices, hotels, leisure and retail with some residential area, in the east of the city centre.
Anchor Chamber visit and bridge crossing of the Forth Road Bridge (1964) - The Three Bridges	Visit of the anchor chamber of the Forth Road Bridge (1964), the fourth longest suspension bridge in the world. Crossing of the bridge on foot, while seeing the Forth Rail Bridge (1889) and the Queensferry Crossing (2017).
Queensferry Community High School, South Queensferry	A visit to the construction site of the South Queensferry High School – including main school building, sports hall, swimming pool and outdoor sports facilities.

Table 2. Brief description of the site visits during the 2016 IPW week

Site visit	Brief description
District Heating Tunneling	A visit to the 300 m long and 3 m diameter tunnel, running below river Main, to accomplish the extension of the energy network.
European Quarter – Urban Development	A tour of the redevelopment of a 60,000m² area comprising offices, hotels, leisure and retail with residential area for up to 30,000 inhabitants.
Riederwald Tunnel Construction site	Visit of the construction site of the tunnel – a key element of a planned motorway link between two motorways in Frankfurt (A66 and A661).
Schierstein Bridge – Reconstruction and Extension	Visit to the construction site of the new bridge to accommodate the traffic volume increase from 20,000 vehicles per day in 1962 to 90,000 vehicles per day in 2012.
The WINX Tower	Visit of the open pit site used for the construction of a 110-metre high tower.

2.2 Pedagogical objectives

In the final day of IPW 2019, the students were asked to collaboratively work towards the preparation of a poster, following conference-oriented format guidelines and present it in front of the organising committee and the other participants. Each group consisted of 10 students of different nationalities. The topic of the poster was to present and discuss the most interesting features (design, construction or maintenance challenges) of one of the visited projects. In the final day of IPW 2016, the students - each group consisted of 6 students of different nationalities - were asked to work on the preparation and the load testing of a skyscraper model. Students were encouraged to search for their own information sources, as well as rely on the information presented in the lectures and provided during the visits. In both events, the best three group projects (posters or models) were selected at the closing ceremony, based on quality of presentation, content and creativity and small commemorative prizes were awarded. Such events are the main means of assessment of the students. It is noted that there is no formal assessment of the students' performance, as the programme is structured as a seminar, aimed in promoting communication and to create networking opportunities among students and staff. Given the open nature of the event in terms of assessment criteria, the educational background of the students does not follow any specific restrictions, such as prerequisite modules. Most undergraduate students are in their 2nd or 3rd year in civil engineering programmes. Given that students are self-funding their participation (traveling and accommodation), they have occasionally participated in multiple IPW events, which have taken place in different countries.

3 Queensferry Crossing – Edinburgh

The three bridges at the Firth of Forth area in Edinburgh are typically included in IPW events and the participants get the opportunity to appraise three engineering projects constructed in three consecutive centuries. In 2019 and due to accessibility reasons, the Forth Road Bridge (1964) was the focus of the visit, however information was provided on the other two bridges as well. Given the abundance of data on the soil conditions and the geotechnical design, the Queensferry Crossing (2017) is presented herein.

3.1 General information of the project

The Queensferry Crossing is a 2.7 km long cable-stayed bridge, which carries the M90 motorway over the Firth of Forth, connecting Edinburgh at South Queensferry and Fife in North Queensferry. It is the third bridge across the Forth at Queensferry, alongside the Forth Road Bridge (1964) and the Forth Bridge (1890), hence making a unique site with three bridges constructed in three consecutive centuries (see Picture 1).

Picture 1. The Forth Road Bridge (centre, left), alongside the new Queensferry Crossing and the railway bridge (Scottishfield.co.uk)

The Queensferry Crossing is the longest three-tower, cable-stayed bridge in the world and the largest to feature cables, which cross mid-span. The particular feature adds more structural stiffness and strength, allowing the construction of more slender towers and decks. The bridge was constructed to replace the existing Forth Road Bridge, which, despite of a planned design life of 120 years, was exceeding its theoretical capacity of 11 million vehicles per year, reaching 23 million vehicles in 2006. Additionally, the inspection programme in the period 2003-2005 revealed a significant loss of strength of the suspension cables, in the order of 8 – 10%, because of corrosion. It was then projected that the Forth Road Bridge would have to close by 2019, unless successful major structural work was carried out. In view of the potential significant disruption in the economic activity in the area, the idea of a new bridge was actively pursued, leading to the completion of its construction in 2017.

3.2 Geological setting

The ground conditions in the project area were determined based on published and historical information, and a project-specific site investigation programme (Jacobs-Arup, 2009). In this report, the term ‘solid’ geology is used to describe the local rock conditions and the term ‘drift’ deposits to describe the superficial soil deposits. These terms are also adopted here.

At the north part, the drift deposits included made ground, alluvial deposits, peat, reclaimed deposits, marine beach deposits, as well as weathered and fresh glacial till. The solid geology in the area mainly consists of quartz dolerite and sedimentary rock formations (i.e. sandstones, mudstones, siltstones, limestones) and thin coal seams. Five faults are mapped across the site with varying dip angles. Groundwater was located within the made ground, natural superficial deposits and bedrock, at variable depths, ranging from 0.3 m to > 25.0, particularly at the northern end. The rockhead (depth to bedrock) was very variable in the area, from ground level (outcrop) to 36 m depth. At the south of the Firth of Forth the drift deposits consisted mainly of weathered glacial till (sandy to gravelly clay) of approximately 2 m thickness. The solid geology in this location of the project is mainly of sedimentary origin, composed of sandstones, siltstones and mudstones. The depth to bedrock varied between 1.0 m to 30 m. Groundwater levels ranged between 1 m to 2 m of existing ground level. The soil profile at the main crossing was a combination of Raised beach deposits, alluvium, granular Fluvio-Glacial deposits over cohesive till. Made ground, consisting of gravel with small proportions of clay and sand, generally less than 2 m thick, was sporadically encountered. The alluvium layer (of maximum thickness of 14 m) mainly consisted of unconsolidated clay and silt, with granular deposits. The till formation consisted of sand and gravel and presented a variable thickness typically less than 6 m, with local thicknesses of 12.9 m. The encountered rock formations were of sedimentary nature (sandstone, siltstone, oil shale, limestone) with coal seams and volcanic tuffs, as well as dolerite, which was intruded by igneous silts of variable thickness (between 0.1 m – 60 m).

3.3 Geotechnical Design

The project spans across an area of variable soil conditions and geological background, hence a variety of geotechnical works was required. The foundations of the main crossing were the main design objective, alongside a series of general earthworks, regarding the proposed mainline and associated road network connections had also to be addressed.

Foundations. - In selecting the most appropriate foundation option, the following key aspects had to be considered:

- Ground conditions, i.e. the depth to bedrock or a competent bearing stratum,
- Water depth and
- Constructability

The selected foundation type depended on the local soil conditions, depth to bedrock, and the type of loads that the foundation would have to carry. Generally, three types of foundations were adopted (West et al., 2019), namely (i) spread footing in modular precast cofferdam (central tower), (ii) caisson and marine sheet-piled cofferdam spread foundations (approach piers, north and south towers) and (iii) land-based spread footings on rock (all in-land approach piers). In Figure 1, a cross section of the bridge with the locations and types of foundations is presented.

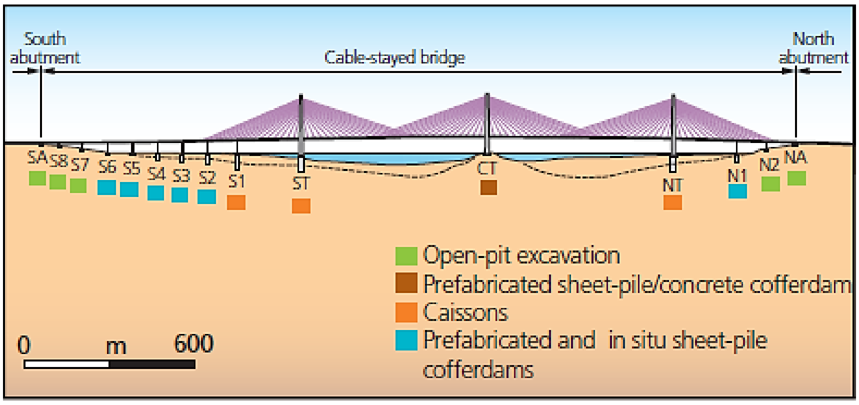

Figure 1. Locations and types of foundations (Climie & Shackman, 2019)

Particularly the 210 m high central tower (CT), was founded directly on an outcropping very strong dolerite pinnacle, with prior controlling blasting to form a suitable foundation pocket to support the prefabricated steel sections that formed a sealed cofferdam. A general view of the central tower enclosure including the temporary horizontal bracing system and diagonal struts is presented in Picture 2. The foundations of the north (NT) and south (ST) flanking towers and pier S1, needed to be constructed in deep water over deep soft soil layers, with bedrock encountered in excess of 30 m, below sea level. For that purpose, circular steel caissons of 25 – 33 m diameter were initially sunk into the seabed, by a combination of dredging and ballasting with concrete. Underwater excavation allowed for the underwater concrete pouring to form a concrete plug, which would enable the construction of a reinforced concrete base. The construction of the spread footings was performed in dry environment. The land-based foundations were all constructed in-situ and consisted of spread foundations.

General earthworks. Apart from the foundations, a series of major or minor geotechnical works were carried out in the project area, mainly in the approach areas. General earthwork design issues included soil cutting slopes, rock cutting slopes, embankment slopes and associated stabilisation measures, such as soil nailing, in-slope drainage, rock dwelling, embankment reinforcement etc. Control and removal of groundwater from the different earthworks was deemed necessary, to guarantee the short- and long-term stability of the works and was achieved through in-slope drainage in the form of racking drains, toe or lined crest channels and rock slope drainage measures. Occasional use of geotextiles was also required to protect in-situ materials. Short (< 2 m) retaining walls were required to support existing structures and walls as well as sporadic piled embankments. Depending on the local soil conditions ground improvement methods were used, such as local removal of soft soils (mainly peat), or soil reinforcement of made ground, sand and alluvial deposits, in order to deal with the potential accumulation of excessive settlements. Band drains, surcharging and geogrid placement were required in some embankment construction locations.

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Picture 2. General view of the central tower enclosure (West et al., 2019)

4 Schiersteiner Bridge – Frankfurt

4.1 General information of the project

The Schiersteiner Bridge (SCHIERSTEINER BRÜCKE) is a 1282 m long road bridge (fly over the River Rhine), connecting the capitals of the federal states of Hessen and Rheinland-Pfalz- Wiesbaden and Mainz (Picture 2). It is one of three bridges, which cross the River Rhine over 125 km, thus emphasizing the importance of the bridge for the regional infrastructure.

The bridge was erected between 1959 and 1962 and consists of six individual structures. It was built as a composite structure with several sequences of prestressed concrete (about 100 m long with a maximum width of 205 m). Upon its completion in 1962, the bridge could accommodate 20,000 vehicles per day without any problem. Nevertheless, due to the dramatic increase of the traffic volume (90,000 vehicles per day in 2012) and the continuous use of the structure for over 50 years, a replacement was deemed necessary. The planned highway is going to have two pavements of three lanes each, of width equal to 14.50 m. The project was planned to be constructed in two phases; namely the construction of the down flow stream from 2013 to 2016 and the subsequent demolition of the existing bridge prior to the construction of the upward flow (2nd three-lane pavement) between 2016 and 2020. The construction started in 2013 and the completion is scheduled for 2020.

Picture 3. Existing bridge with new construction in progress (Samstag & Stremmel, 2016)

4.2 Geological setting

The bearing subsoil of the bridge line consists of marine Tertiary sediments (Oligocene) that consist of a non-homogeneous, stiff and over-consolidated clay with embedded limestone bands of varying thickness. This layer is underlain by limestone and dolomite layers, as well as algal reefs, marly calcareous sands and silts and marly clay. The rather thin top layer consists of quaternary sand and gravel. Especially the top 40 m of the Tertiary sediments consist of clay layers, which are geologically defined by brackish water snails (Hydrobia). In greater depths, the limestone layers are geologically defined by shell-type Corbicula formations. The above soil conditions are typical of the subsoil encountered in Frankfurt (Mainz Basin) and the mechanical behaviour of the soil can -in principle- be compared to that of London Clay (deposited during the Eocene epoch). Note that the Eocene epoch stretches from the end of the Paleocene Epoch to the beginning of the Oligocene Epoch, which partially explains the similarity to the Tertiary deposits in Frankfurt.

Near the river borders and the floodplain, the Tertiary subsoil is covered by Quaternary Rhine sediments that consist of sand and gravel, mixed with Aeolian sediments and anthropogenic sediments of World War II demolition waste of the formerly destroyed cities nearby. The inclination of the Tertiary layers is south to south-west. Moreover, there is great variability in both the vertical and horizontal direction, with a direct effect upon the shear strength and bearing capacity of the soil.

Based on the above, the local soil conditions are summarised as follows:

- Small water depth and only small layer thickness of the river's soil cover;
- Non-homogeneous, stiff and overconsolidated clay;
- Immediate extreme changes of subsoil strength at a small scale from very hard to chemically weathered;
- World war II demolition waste;
- Big changes of the hydraulic conductivity with depth.

4.3 Geotechnical Design and Challenges

The old and new construction will be fully supported by floating pile foundations (Pelke & Dieter, 2013). Generally, two types of pile foundations with sheet-piled cofferdam are adopted, namely (i) land-based, (ii) pontoon-based on the river. The bored pile foundation is constructed in a steel sheet piling support chamber (cofferdam), as presented in Figure 2 and Pictures 3 and 4. The first part of the bridge side will be built onshore, on auxiliary supports of 133 m in length and 2500 tons in weight. The assembly component is pushed 87 m over the pillar up to 40 m above the shipping lane, meaning that this part of the pile foundation will have to withstand many load changes.

For all areas of civil engineering, this is a demanding and complicated task, especially for geotechnical engineers when considering the active settlement of the clay layers and the danger of high settlements and tilting of the structure itself. As the boundaries of soil layers are dipping, the thickness of the settlement-active clay varies below the foundation structures. When planning foundations, under these difficult conditions, a major task is the reduction of settlements and differential settlements of the structures as well as adjacent buildings. The aim is to also ensure their safety and serviceability under live load criteria and furthermore when considering the option of re-use of foundations.

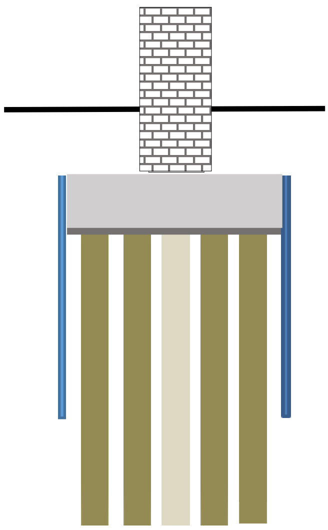
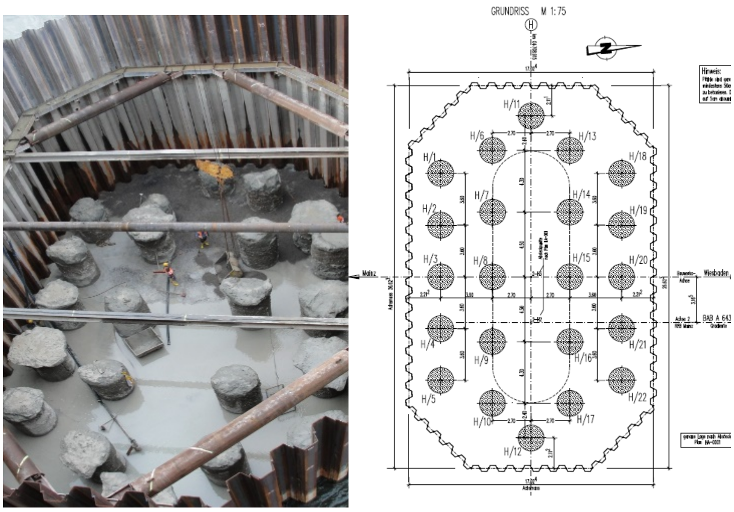


Figure 2. Sketch of the pile foundation (Samstag & Stremmel, 2016)

Picture 4. Diameter of piles: 1.80 m, Length: 30 m (Samstag & Stremmel, 2016)



Picture 5. Sheet pile chamber, piles and under water concrete floor (Samstag & Stremmel, 2016)

5 Identified issues in curriculum design

The previously presented large-scale projects involve a wide variety of geotechnical design issues, such as foundation design, embankments, slope cutting, retaining walls etc. Each one of the above works involve multiple levels of analysis and design, which span different construction phases of a project and may even require different design approaches depending on their temporary or permanent character. It is acknowledged that the previously presented information may not be fully appraised by the IPW participants through a half-day visit and a 45-min lecture. As IPW is a European collaborative network of institutions, the main objective is to provide participants the opportunity to expand their academic and professional network, realise the international nature of their profession and appraise the engineering challenges, construction practices and methods used abroad. As a result, the programme is built around activities (site visits, invited lectures from established engineering professionals) that target student engagement and participation. In the aftermath, it is noted that many students have successfully applied for job positions to companies involved in the site visits that had been organised. Moreover, since the majority of students come from non-English speaking countries, they also have the opportunity to practice their English skills, as they are invited to collaborate in multi-national groups on the final project. The above features are believed to compose a useful set of basic but necessary - transferable - employability skills, which the students possess upon graduation from an undergraduate programme and which can further grow, as part of their ongoing professional development. Based on student feedback, students are happy to increase their awareness of the profession in other countries, learn about the hosting institution and country, and more importantly understand how civil engineering theory is put into practice through site visits in a foreign country.

Programmes such as the International Project Week underpin the purpose of problem-centred curriculum design in multiple levels. Considering their geotechnical background, the authors here attempt to identify learning objectives that could be included in such events so that their technical character is enriched. Additionally, indicative means of accomplishing the above objectives are identified. The local geology, stratigraphy and composition of the soil greatly determine the level of complexity and difficulty in design and construction of any civil engineering project. Hence, understanding the local geological and soil conditions is fundamental from the early design stages of a project and normally geotechnical engineers closely collaborate with engineering geologists to properly account for the local geological conditions. A minimum knowledge of engineering geology/rock mechanics is therefore believed to contribute to the interdisciplinarity of modern academic education and benefit young geotechnical engineers in their adaptation in a fast-moving international professional environment. Building upon the geological information of the presented projects, a series of learning outcomes can be introduced to a technical geology module, such as: (i) appraising the processes involved in rock formation and categorising rock formations in terms of increasing durability, (ii) identifying rock formations susceptible to dissolution (i.e. limestone), which is associated with the creation of sinkholes and a significant subsidence hazard, (iii) discriminating between permeable (sandstones) and impermeable (siltstones) rock formations or (iv) understanding the effects of fault orientation upon underground structures or slope cutting. Bringing into the classroom examples as the previously presented projects and using them as case studies significantly promotes the above objectives. Moreover, as part of class projects, students can be asked to search for additional information or even compare the geological conditions between case studies.

Young graduates are typically able to perform basic calculations, such as the bearing capacity and settlements of a foundation or the factor of safety against sliding and overturning of a retaining structure. However, they are often unaware of how the construction process affects the initial geotechnical design. More specifically, a great majority of them, do not fully perceive that multiple design issues may affect a project, such as the construction of temporary retaining structures prior to the construction of a spread foundation. Similar issues may require the adoption of different design approaches, namely the safety factor for a temporary structure may be lower or it may not be required to be analysed for seismic loading conditions. To that end, construction-related topics can be added to relevant geotechnical modules (such as foundation design). For instance, the construction sequence of the north (NT) and south (ST) towers of the Queensferry Crossing provide a good basis for further discussion in the classroom regarding the challenges involved in underwater excavation, or the logistics involved in dredging and ballasting with concrete. The development of short class-projects where students seek further information on these or similar issues and even perform preliminary engineering and cost calculations can also significantly enhance their employability skills and broaden their geotechnical engineering awareness.

The previously identified learning goals and the proposed delivery approaches (lecture notes and class-projects) are only indicative and provide a first level of action that contributes to the establishment of a strong technical background. Apart from that, and given that modern employers seek self-motivated candidates with a global mind-set, good interpersonal skills and teamwork attitude, a problem-centred approach, following Wood (2003), in curriculum design can be very beneficial. Namely, specially crafted learning activities, such as international exchange programmes can serve this purpose. It is also vital that they are appropriately tailored and oriented towards developing key industry-related attributes and professional skills of the participants.

6 Concluding remarks

In the present paper, the role of international exchange visits, such as the International Project Week (IPW) in the geotechnical undergraduate education is explored. The authors, who are involved in the organisation of the IPW event, initially give a description of the programme and attempt to trace its benefits upon the students, which revolve around networking, obtaining conceptual knowledge on a broad spectrum of civil engineering projects and exploring opportunities to work abroad. The authors further identify two large-scale projects, which are typically visited as part of the programme. They present their main geotechnical characteristics and construction challenges, in order to trace potential areas of development in the design of geotechnical modules and investigate pedagogical means of achieving them. To that end, they recognise that international exchange visits can play a crucial role, when a distinct technical character is added and the experience is further capitalised into the classroom, in the form of relevant learning activities. That way, undergraduate students not only are they exposed to an international environment and develop a global mind-set during their visit but they can further enhance their technical background and obtain a more inter-disciplinary education.

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Authors' bios

Vasiliki Dimitriadi, Edinburgh Napier University, Scotland, UK

Dr. Vasiliki Dimitriadi is a Lecturer (Assistant Professor) at Edinburgh Napier University, Scotland, UK, who specialises in the field of Geotechnical Engineering. She graduated in civil engineering from National Technical University of Athens (NTUA) (5-yr degree), obtained a M.Sc. degree from University of California Berkeley, USA, and a Ph.D. degree from NTUA. Between 2014 and 2018 she worked as a geotechnical consultant in Athens, Greece, and has obtained significant experience through her involvement in a wide spectrum of civil engineering projects. Most of her research experience focuses on earthquake-induced liquefaction and the response of shallow foundations in a liquefaction regime. Since joining Edinburgh Napier University in 2018, she has further expanded her research interests in ground improvement methods for foundation remediation under static conditions. She is also actively pursuing educational research opportunities, with a focus on project-based learning and is interested in creating opportunities for academia – industry collaborations.

Kurt Kliesch, Frankfurt University of Applied Sciences, Germany

Dr. Kurt Kliesch is a professor at the Frankfurt University of Applied Sciences and the head of its geotechnical team. He graduated in civil engineering (Dipl.-Ing.) from University of Karlsruhe (now KIT, Karlsruhe), and obtained a Ph.D. at University Darmstadt. In 1984-1986 and 1990-2001 he worked in Germany. His main technical interests and experiences are geotechnical engineering of retaining walls and stabilization of landslides. Professor Kliesch's research focuses on analysing groundwater monitoring in the urban setting of Frankfurt and on analysing the bearing behaviour of displacement piles. Due to his strong passion for teaching, Dr. Kliesch stimulates students' international exchange interests, e.g. by supporting and pushing the concept of Interdisciplinary Project Work, IPW. Dr. Kliesch and his team were awarded a "Youth builds Europe" award from the Prof. Joachim Lenz Foundation for their Polish-German project "Flood Control of the Palace of Kurozweki, Poland."

Master's Degree on Soil Mechanics at CEDEX: An Example of Collaboration among Government, Academia and Industry

F. Pardo de Santayana, E. Asanza, J.A. Díez & M. Muñiz

Laboratorio de Geotecnia-CEDEX, Madrid, Spain
F.pardo.S@cedex.es, enrique.asanza@cedex.es, juan.A.diez@cedex.es, mauro.muniz@cedex.es

ABSTRACT: The Spanish research centre CEDEX (*Centro de Estudios y Experimentación de Obras Públicas*) has been organising an international postgraduate Master on Geotechnics since early 1980s, evolving from a 3-month course, forged as a tool of international cooperation with Latin American developing countries, into a reputed postgraduate master (now with ~1000 alumni). The following features stand out, among others: an enduring onsite course in Spanish, varied affiliations (industry, administration and academia), engagement of its lecturers and the contribution of host universities (UPM and UNED), technical societies and alumni (nearly 25 % of the lecturers are alumni). The paper describes: its origin, the various policies the Master has followed; the syllabus evolution and the assignments; and the assessment of the performance of the students. A retrospective review is included as well. To the authors' experience, an onsite intense course with: (a) a sound syllabus and varied lecturers; (b) a proper environment (students a bit under pressure, yet at ease); and (c) weekly assignments that prompts cooperation, is a successful combination.

Keywords: Master's degree, soil mechanics, geotechnical engineering, Spanish language

1 Introduction

CEDEX is a unique public research centre attached to the two Spanish ministries responsible for infrastructures, transportation and environment. CEDEX has been organising uninterruptedly a course taught in Spanish since early 1980s that has evolved over the years into a postgraduate master on Geotechnics, that annually selects between 25 to 30 international students (to date, ~1000 alumni), with recognition in the Latin American countries. The objective of this paper is to describe, discuss and gain insight into: the endurance of the Master over its evolution; survival after the cut-out of grants and the economic downturn severely affecting construction in Spain; commitment of lecturers from 3 areas of affiliation (industry, administration and academia); engagement of the Spanish universities; and development of alumni networks that enhance the access to an international labour market and calls for scholarships. The current structure of the Master, the driving force that caused the Master to come into being, its syllabus, the coursework and the class material are described and examined as well. Besides, educational choices in Spain with respect to the economic context over the past four decades will be briefly discussed. Finally, some retrospective thoughts are shared with the reader.

2 Current structure and features of the Master's degree

2.1 Objectives

The main objective of the Master is not to offer a regular university degree, but rather to provide an as much as possible comprehensive professional education in the field of geotechnics, from theory to practice, in order to advantageously prepare the students to enter the labour market. A few, however, take the chance of joining a research project. Surely, decades ago, when access to information was scarce and the vast majority of students came from Latin America, the purpose was as well to provide with as much information as possible to the students, some of them having vocation for academia.

The Spanish students, very few until mid-90s, began to be gradually interested in the course. In fact, in the last 10 editions Spanish students have represented on average 55% of the class. Among all the applicants, a maximum of 30 students are selected with academic and professional criteria, and to a lesser extent, of geographical diversity. Spanish language skills are required to attend the course.

2.2 The organizing institutions

2.2.1 CEDEX (*Centro de Estudios y Experimentación de Obras Públicas*)

CEDEX (Centre of Studies and Experimentation for Public Works) is a government-owned institute attached to the Ministry of Development (*Ministerio de Fomento*) reporting to the Secretary of State for Infrastructure, Transport and Housing, and with functional service to the mentioned Ministry and the one for Ecological Transition (*Ministerio para la Transición Ecológica*; formerly, Ministry for Environment). When in 1957 the *Escuela de Ingenieros de Caminos, Canales y Puertos of Madrid* (that dates back as early as 1802), then the only School of Civil Engineering in Spain, was transferred from the Ministry of Development to the Ministry of Education to become part of the new *Universidad Politécnica de Madrid* (UPM), the School's laboratories, distributed in different nearby buildings, were so well equipped that the Ministry of Development managed to keep them, on the grounds of strategy, technical and research assistance. This set of laboratories was the origin of CEDEX (ports, hydraulics, geotechnics, transportation, structures and materials, etc.). Maybe because of that, the institution has always kept certain inclination for education and strong bonds to that School. In fact, a few outstanding engineers used to serve then both as heads of CEDEX Laboratories and as professors at the School.

CEDEX offers unique testing facilities, provides high-level consultancy, contributes to standardisation, does applied research and technological development and, ultimately, promotes conveyance to industry. In fulfillment of its commitments, CEDEX uses resources for discussion, training and educational actions, which have gained national recognition over the years, becoming a meeting point and forum on civil and environmental engineering among contractors, practitioners and scholars. Furthermore, the secretariats of a number of technical societies are based in CEDEX (regarding geotechnics, three National Societies: for Rock Mechanics, for Soil Mechanics and for Geosynthetics).

The Geotechnics Laboratory (*Laboratorio de Geotecnia*) has been the venue of the master for decades. This Laboratory is in charge of issues dealing with foundations, earthworks, soil and rock mechanics, and in general, the civil engineering activities linked to the ground, mainly at the request of the National Port Authority (*Puertos del Estado*), the administrations for railways, roads and water resources - *Administrador de Infraestructuras Ferroviarias*, (ADIF) & *Dirección General de Carreteras*, *Dirección General del Costas* & *Dirección General del Agua*. Nonetheless, the Geotechnics Laboratory stands out in research, sometimes in collaboration with other institutions. Proof of this is the considerable number of PhD theses (more than 15 in recent years) that have been carried out in the Laboratory, alone or in collaboration with universities.

2.2.2 UNED (*Universidad Nacional Española a Distancia*)

UNED (National Distance Education University), founded in 1972, is the only off-campus public university in Spain; besides, it is one of the very few universities that, unlike the vast majority in Spain (transferred to regional governments), is attached to a Ministry (Science, Innovation and Universities). UNED (https://www.uned.es/universidad/inicio.html) is the host University of the Master since 2012.

UNED has the largest student population (>260 000) in Spain and is one of the largest universities in Europe. It offers 27 bachelor´s degrees, 76 official university master's degrees and 19 doctoral programs adapted to the European Higher Education Area (EHEA). Even though its headquarters are based in Madrid, it is present nationwide in the form of 61 associated centres (campuses) and more than 100 extensions and classrooms, where tutoring takes place and also serve as venues for the onsite exams. It also has offices abroad, in 13 countries: 6 in Europe; 6 in America; and one in Africa.

2.3 Other supporting agencies or organizations

AETESS (*Asociación Española de Empresas de la Tecnología del Suelo y del Subsuelo*) (https://aetess.com/) was established in 1977 with the aim of supporting an emerging market for the largest national contractors dealing with ground engineering (special foundations, soil improvement and treatment), embracing commitment to quality, safety and professionalism. Thus, AETESS shares its technical activities with public institutions, associations and standardisation entities. Accordingly, AETESS is the Spanish member of the European Federation of Foundation Contractors (EFFC), which represents 370 foundation contractors of 16 European national federations.

With regard to the Master, AETESS has been strongly engaged for decades, both on hosting on site visits and conferences. Lectures on ground improvement techniques are addressed by its highly experienced engineers. In fact, the Master itself is its basic source of recruiting qualified personnel. No wonder that many of the technical managers of its member companies are alumni.

AECID (Spanish Agency of International Cooperation for developing), attached to the Ministry of Foreign Affairs, was founded in 1988 as an entity for management of policies in the scope of international cooperation for development and combating poverty. Even though AECID has not collaborated actively since 2012, it is fair to acknowledge its support over the past decades, because AECID used to grant every edition between 10 to 20 outstanding students from abroad, covering the basic expenses of the Master (accommodation, cost of living and academic fees). Hence, it was a crucial agent in promoting the Master in Latin America for decades.

2.4 The syllabus and lecturers

2.4.1 Syllabus

The course is arranged into a compulsory attendance period, being held from February to June, plus a 3-month period, from July to October, during which each student has to write, under the tutoring of a lecturer, a dissertation to be presented before a board of examiners by October. The classroom period is scheduled daily from 9:00 to 13:30 on weekdays. An ordinary daily timetable would consist of: a first lecture (2h, including a short break), a 30-min break and a second lecture (same format). Afternoon lectures (15:00 to 17:00) are scheduled from 2 to 3 days per week approximately.

The classroom period is divided into three units, each subdivided into modules (each is one-week long). The syllabus is supplemented with sessions on advanced geotechnics. The content of the modules per unit and the sessions of Advanced Geotechnics are shown in Table 1.

Lessons on principles of soil and rock mechanics are addressed as if the students had not previous knowledge; yet, concepts are conveyed in much deeper detail than a regular university course. Lectures on geothermal issues, off-shore foundations, reservoir geomechanics and Eurocode 7 were included 5 years ago, whereas some lessons on structural design of foundations have been reduced.

Table 1. Content of the modules, arranged into units and sessions on advanced geotechnics

First Unit	*Second Unit*	*Third Unit*
Principles of soil mechanics I	Shallow foundations	Earthworks and fills
Principles of soil mechanics II	Deep foundations	Tunnels
Principles of soil mechanics III	Slope stability	Soil improvement
Field investigation	Earth retaining walls	Dam & tailing geotechnics
Principles of rock mechanics		Numerical methods and modeling
(+ 3 lab sessions)		Environm./Energy Geomechanics
		Soil dynamics (+ lab session)
Sessions of Advanced Geotechnics: (*nº of lectures in brackets*): clay mineralogy (1); foundations of offshore structures (2); Geotechnical reliability and risk assessment (1); Constitutive models (2); Critical State Theory (4); Eurocode 7 (1); Limit State: upper and lower bound theorems (2); unsaturated soil mechanics (4); reservoir geomechanics (2)		

2.4.2 Lecturers

Nearly 25 % of the lecturers are alumni. As shown in Table 2, the affiliations of the contributing lecturers is varied. Lessons dealing with principles of soil and rock mechanics are taught mainly by the Geotechnics Laboratory Staff (~45 % of all the lectures), and to a lesser extent (~15%), by faculty members from the School of Civil Engineering (UPM). Some of the topics concerning singular machinery (hydrofraise, sheet diaphragm wall technologies, grouting, TBM, singular borings, etc...) are commonly addressed by experts of AETESS, who apply the theory to their everyday professional work. Many of them volunteer to be a tutor or a member of the board of examiners of the theses. Students have then a unique opportunity to show their capabilities to enter the labor market.

Table 2. Affiliations of the lecturers (~75 in total) that contribute in the Master (last 5 years)

Administration & government owned institutes (60 %)
Geotechnics lab. (core lecturers, 45 %) + Structures & Materials lab. (CEDEX)
Instituto Geológico y Minero de España (IGME)… ≈*National Geological Survey*
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) (≈CEDEX, but attached to the Ministry of Science, Innovation and Universities)
Centro Internacional de Métodos Numéricos en la Ingeniería (CIMNE)
Ministerio de Fomento, Dirección General de Carreteras (roads)
Ministerio de Medio Ambiente (Dirección General del Agua) ≈ water resources
Confederación Hidrográfica del Ebro, ≈River Ebro Authority
Bundesanstalt für Materialforschung und -prufüng (BAM) ≈German counterpart of CEDEX
Contractors and engineering offices, 18%
From members of AETESS: ~8%
Companies: REPSOL, Ferrovial, Acciona, Arup, Euroestudios, Geobrugg ~8%
Offices: Uriel & Asociados, Túneles y Asistencia Técnica (Tunelestat) 2%
Academia (in brackets nº of lecturers) ~22% *(the Spanish universities and faculties below are public)*
Civil Engng. Schools: Madrid (8); Santander (2); Barcelona (3); La Coruña (1); Granada (2); Valencia (1) *Other:* Geology Faculties: Madrid (1); Mining Schools: Madrid (1); Vigo (1) *Engng. Schools from abroad:* University College of London (1); Texas A&M (1)
Approximately 75 lecturers in total; nearly 25 % of the lecturers are outstanding alumni.

Fortunately, research groups from nationwide universities take over lessons in their own field of expertise (i.e. CIEMAT and UPC on unsaturated soils; UPM and CEDEX on rock mechanics; and CEDEX and the group "m2i" in UPM and lecturers from UC-Santander, on numerical modeling).

Despite the extra effort on organisation, bringing together lecturers from different affiliations and areas is high rewarding for the student; such variety seems hard to attain in a master’s degree offered by universities. Another asset is the flexibility to change or add lecturers over the years, and, for instance, to introduce new technologies in the industry and, ultimately, keeping the syllabus updated.

2.5 Coursework and criteria of evaluation

2.5.1 Coursework, geotechnical software and continual assessment

Students are handed out weekly individual assignments (problem solving), generally, one per module, to make the continual assessment easier. With the aim of getting the most of theoretical lessons, worked examples are explained in detail on the blackboard within the following days. Assignments, though individual, prompt fruitful discussion among classmates in their struggle to work out the result. In addition, students are presented with a few practical assignments to work in groups to promote collaborative skills. The following assignments of this kind are worth mentioning: (a) a field day trip to a rocky outcrop where a detailed geomechanical survey has to be carried out with field tools, plus a rewarding cultural visit in the afternoon (to the Escorial Monastery); (b) a drill on drawing up an economic-technical report for a pretend client (the teacher) offering an underground geotechnical project (explained in the classroom with guidelines on how to prepare it); the students (pretend bidders) have to make a short presentation as well, facing questions from the "client"; (c) case histories (one shared by 5-6 students) addressed by CEDEX in the past; the group is requested to come up with their own geotechnical solution or design.

Particularly, the assignment relating to the module on numerical modeling includes classroom tutorials of Midas GTS NX and several exercises to be solved in groups. The choice of GTS NX resulted from the chance of having at CEDEX's disposal a free fully unrestricted license per student throughout their enrolment; in the past, the student version of PLAXIS was used instead to solve simple cases. In any case, PLAXIS, DIPS, SWEDGE and GEOSLOPE are briefly introduced to students. Any developer of geotechnical software is welcome to contact the Master's academic board for educational purposes.

There is certainly an open debate (to be addressed elsewhere) about the point of making software available to students when they still can hardly solve simple problems by analytical methods.

The coursework described above comprises a continual evaluation that represents 20 % of the global assessment of the student's performance during the attendance period, whereas the average score of the three exams (at the end of each unit) is 80 %. The weighed marks resulting from these two is 70% of the total and the Master's thesis (written document + presentation) is 30%.

2.5.2 Class materials and reference books

Upon enrolment, students receive the course e-documents (basically, the lecturers' slides from the previous edition, in pdf format, in Spanish as a rule), a series of relevant papers, an access card to CEDEX facilities and 3 easy-to-read text books (in Spanish), useful as a basic supplement for the 1st unit. The 4-volume seminal treatise "*Geotecnia y Cimientos*" (coordinated by Prof. Jiménez Salas, see Section 3.1) used to be the reference book until a decade ago. Many Latin American alumni still evoke the anecdote on departure at the airport about the baggage overcharge due to overweight of this 7.3-kg treatise. Nowadays, a source of knowledge so heavy as compared to a tablet is unfairly unwelcome. Nonetheless, several copies of this valuable treatise are available in the classroom.

Apart from well-known technical books written in English, technical writings in Spanish are strongly promoted from the academic board, as a means of counterbalancing the unnecessary invasion of anglicisms and of joining forces to strengthen the terminology within the Spanish-spoken community. Other sources at the disposal of the students in the classroom are specific courses or conferences held in CEDEX (on paperback). Digital sources in Spanish can be found at: *Revista de Obras Públicas* (http://ropdigital.ciccp.es/); journals of the Spanish (https://semsig.org/boletines-de-la-semsig/) and Portuguese (https://semsig.org/revista-geotecnia-listado/) Societies of Soil Mechanics, as well as CEDEX-AETESS conferences and sessions (https://aetess.com/tienda/) and *Revista Ingeniería Civil*, edited by CEDEX, (http://www.cedex.es/CEDEX/LANG_CASTELLANO/DOCU/PUBLICACIONES/RINGCIVIL/). This journal devoted in 2017 a special issue to the Master, including as papers summaries of the most outstanding master's thesis of that year. The academic board, in fulfilment of the Master's ethos, welcome other sources in Spanish coming from Latin America. Finally, students from abroad have the opportunity to become familiar with the Spanish technical guides, standards and, in the recent years, with Eurocode 7.

2.6 Facilities and cost

The Geotechnics Laboratory is located in an enclosure adjoining the South limit of the Retiro Park, the green area of the city centre. Sometimes student get together there for a picnic or a midday break. CEDEX is within easy reach of all the main cultural sites and means of transport. The building is fully equipped, with a canteen, WIFI access and a geotechnical library. Students have the chance of visiting the different testing rooms and see some field exploration equipment of the Laboratory. The cost of the Master is 6000 euros, which covers tuition fees, course documents, academic trips, schooling, library services, reference books and attendance to conferences. Students just need a budget for the cost of living and accommodation. It is compulsory for students to have a student visa.

3 A long-lasting Master on geotechnics at CEDEX

3.1 How it came into being; *initial conditions*

The origin of the master's degree must be sought in 1965 in the Laboratory of Transport and Soil Mechanics of CEDEX (currently, the Geotechnics Laboratory), with the so called “Specialization Course in Transport and Soil Mechanics for Latin American Engineers”, carried out with the collaboration of the Institute of Spanish Culture and the School of Civil Engineers (*Escuela de Ingenieros de Caminos, Canales y Puertos*) of the Universidad Politécnica de Madrid (UPM), in Madrid, still the only Civil Engineering School in Spain.

In the early 1980s, Professor José Antonio Jiménez Salas, the genuine pioneer of Geotechnical Engineering in Spain, conceived a course exclusively on geotechnics for Latin American postgraduates at the School of Civil Engineers of Madrid (Fig. 1), with the aim of promoting technical development abroad. At that time he combined his teaching duties as professor of Geotechnics and Foundations in this School with the post of head of the Geotechnics Laboratory at CEDEX.

On reading the biographical notes of Prof. Jiménez Salas in the tribute book by his epigones (SEMSIG, 2000), the special issue of the *Revista de Obras Públicas*, as well as in the tribute held in the *Real Academia de Ciencias* on occasion of his centenary (http://www.rac.es/4/4_4_1.php?id=109), his devotion for education was evident. His international prestige and extraordinary teaching skills and the highly qualified group of fellow researchers who assisted him, from the School and the Geotechnics Laboratory of CEDEX, led to the dissemination of the course in the countries with linguistic bonds.

Figure 1. Students and coordinators of one of the first International Courses on Soil Mechanics and Foundation Engineering in the early 1980s right in front of the School of Civil Engineers of Madrid

3.2 From the School of Civil Engineering to CEDEX; *primary consolidation*

After its germinal stage at the School, the VI International Course on Soil Mechanics and Foundation Engineering (1988) was transferred to the Geotechnics Laboratory of CEDEX; Then, say, its “primary consolidation” started as a course under the direction of Prof. Carlos Oteo, at that time Director as well of the Geotechnics Laboratory. Prof. Jiménez Salas remained engaged with the course over the following editions and taught until mid-90's. Figure 2 shows a welcoming session in CEDEX (c. 1988).

3.3 Becoming a Master and joining a host university; *secondary consolidation*

In 1996 Dr. Cuéllar was appointed Director of the Laboratory and the course kept evolving, extending its content (critical state, worked examples, limit bound theorems, software practice, etc…). Since 2000, on the occasion of another extension of the teaching burden (from 3,5 to a 5-month length), the course certificate obtained the status of master's degree. During those years the Master started to steadily draw Spanish graduates' attention, in a context of prosperity and growth of the construction activity, and therefore, of no distress of graduates for getting a job at any cost.

Figure 2. Welcoming session (c. 1988): left to right, Mr. Marcelo Rodríguez (CETA); Prof. Jiménez Salas; Ms. Isabel Vilches (CETA); Prof. A. Serrano (head of the CETA); Prof. Carlos Oteo (Director of the Geotechnics Lab)

With the advent of the Bologna process, CEDEX joined forces again in 2009 with the Polytechnic University of Madrid (UPM) to organize the course, evolving into a postgraduate Master's degree, being compulsory since then to defend a master's thesis. According to the European Credit Transfer and Accumulation System (ECTS) the Master reached an equivalence of 60 credits. In the 2012 edition the Master shifted to UNED as a host university, maintaining all its standards and structure.

UNED, being a state (non-regional) university, attached to the Education Ministry, grants even more freedom to the academic board for choosing the most suitable lecturers, whatever their affiliations. Table 3 summarizes the key features of the evolution of the Master.

4 Discussion; a retrospective review

4.1 On the heterogeneity of the students

Another feature of the Master is the heterogeneity of the students, which is manifold: the variety of degrees of the applicants (the course is aimed at civil engineers, geological engineers, mining engineers, geologists, geophysicists and related professions), hence the difficulty for the selection committee when comparing CVs; the ample range of ages, and in turn, their expectations (from recent young graduates, enthusiasts for geotechnics with undefined expectations, to senior professionals seeking, perhaps, a recycling course due to uncertain prospects); their uneven background on Maths and Physics. Pondering this factor is essential so as to guide lecturers on how to convey the concepts to the class. Thus, after the welcoming session, in every edition students are requested to fill in a questionnaire with elementary questions (physical units, forces and bending moments of a cantilever beam, the surface of a sphere, the true meaning of gradient, etc...). In doing so, those in need of going over basic concepts come to terms with their weakness for completing the Master successfully.

4.2 The human factor: classroom learning, technical visits/trips, group assignments

Several field trips are organized, including a two-day ice-breaking technical visit during February and a 5-day trip, typically in May. During this trip relevant geotechnical ongoing work in construction sites in a region of Spain are visited, guided by lecturers involved in them. The aim of these field trips is dual: to offer true contact with geotechnical activity and techniques on site; and to foster fraternization among not only class-mates, but as well with professionals and alumni working on site and lecturers. Besides, a casual professional workshop in the classroom is programmed by early June, with panelists from AETESS and national societies and presentations of outstanding alumni (about recent geotechnical projects or even their own experience). In the long run, all this interaction forges a network and bonds really fruitful in the students' professional career.

Table 3. Summary of the evolution of the Master on Soil Mechanics and Geotechnical Engineering

	Course U.P.M.	**Course at CEDEX**		**Master**	**Master 60 ECTS**		
Years	1982-1987	1988-1997	1998-1999	2000-2008	2009-2011	2012-2016	2017-2019
Director	J.A. Jiménez Salas	C. Oteo (until 1997)	V. Cuéllar	V. Cuéllar (until 2006) F. Pardo de Santayana	F. Pardo de Santayana	F. Pardo de Santayana	F. Pardo de Santayana
Coordinator	C. Oteo	F. Pardo de Santayana (until 1992) J.C. de Cea	J. Sáez	J. Sáez (until 2006) J.Estaire A. Perucho	J. Estaire A. Perucho	E. Asanza J. González-Gallego	E. Asanza J. A. Díez C. Higuera
Venue	School of Civil Engng. (UPM)	Lab. Geotecnia CEDEX		Lab. Geotecnia CEDEX	Lab. Geotecnia CEDEX	Lab. Geotecnia CEDEX	Lab. Geotecnia CEDEX
Degree title	Course (3 months)	Course (3,5 months)		Master (5 months)	Master 60 ECTS + Master thesis	Master 60 ECTS + Master thesis	Master 60 ECTS + Master thesis
Role of univesity	course UPM	Collaboration UPM		Collaboration UPM	Master UPM	Master UNED	Master UNED
Remarks	All students from Latin America	Lab sessions still at the School of Civil Eng. Very few Spanish students		Growing interest among Spanish engineers	~ 50 / 50 geographical origin (from abroad /Spanish)		

Figure 3 shows a flyer of the upcoming edition (38th) and nationalities of students since 1988. Despite the cultural bonds among Ibero-American countries, sharp differences of idiosyncrasy, social background and barriers are found among the students.

Figure 3. Flyer of the 2020 edition (38th), and of students' nationalities since 1988

Unlike in soil mechanics, in this respect, heterogeneity among peers is an unpaired source of learning that is taken in naturally by socialising for more than 5 months. Thus, Figure 4 evokes the aphorism "*a picture is worth a thousand words*". It is worth mentioning the conference promoted by Prof. Marcelo Sánchez (Texas A&M University, Prof. at the Civil and Environmental Engineering School) and his classmates (his life-long friends) of the 1994 edition, happily sponsored by CEDEX in 2017. That conference served as well as a reunion in the venue where they first met, which determined the course of their lives. The current and two former directors of the Master and several alumni were speakers at that successful conference (http://www.cedex.es/NR/rdonlyres/18E1E2CF-7366-4CE3-86BF-16E3268DDC1E/143440/FolletoSeminarioMaster94_v2.pdf).

Figure 4. "A picture is worth a thounsand words"; A) Bridge "Constitución" (Cádiz); B) in class; C) near the El Escorial Monastery, after the geomechanical survey; D) visiting a tunnel for the high-speed line in Galicia

4.3 Economical context in Spain over the years and educational choices

Figure 5 shows a timeline since 1965 with relevant milestones. The red coloured background graph shows the annual consumption of cement (10^6 tonnes) in Spain, sometimes used as reference of the activity in the construction industry. The sharp growth and the subsequent drop identify the economic downturn that affected worldwide and really badly this industry in Spain. The names of the most renowned schools of civil engineering are labelled above the graph of cement consumption, approximately on the year of the 1st graduation. The lower part of the figure shows the educational choices other than a regular degree at university. Two events have disrupted the traditional balance of university choices: the advent of degrees on Engineering Geology in the late 90's); and the uncontrolled thriving of degrees in civil engineering as a result of the Bologna process.

A sound postgraduate course is a fairly good ally for those determined to work in the core of civil engineering. The Master has endured throughout all the past difficulties and is still coping with them. Yet, in a global world, when any Ibero-American geotechnical company tries to open business abroad, alumni are good choices.

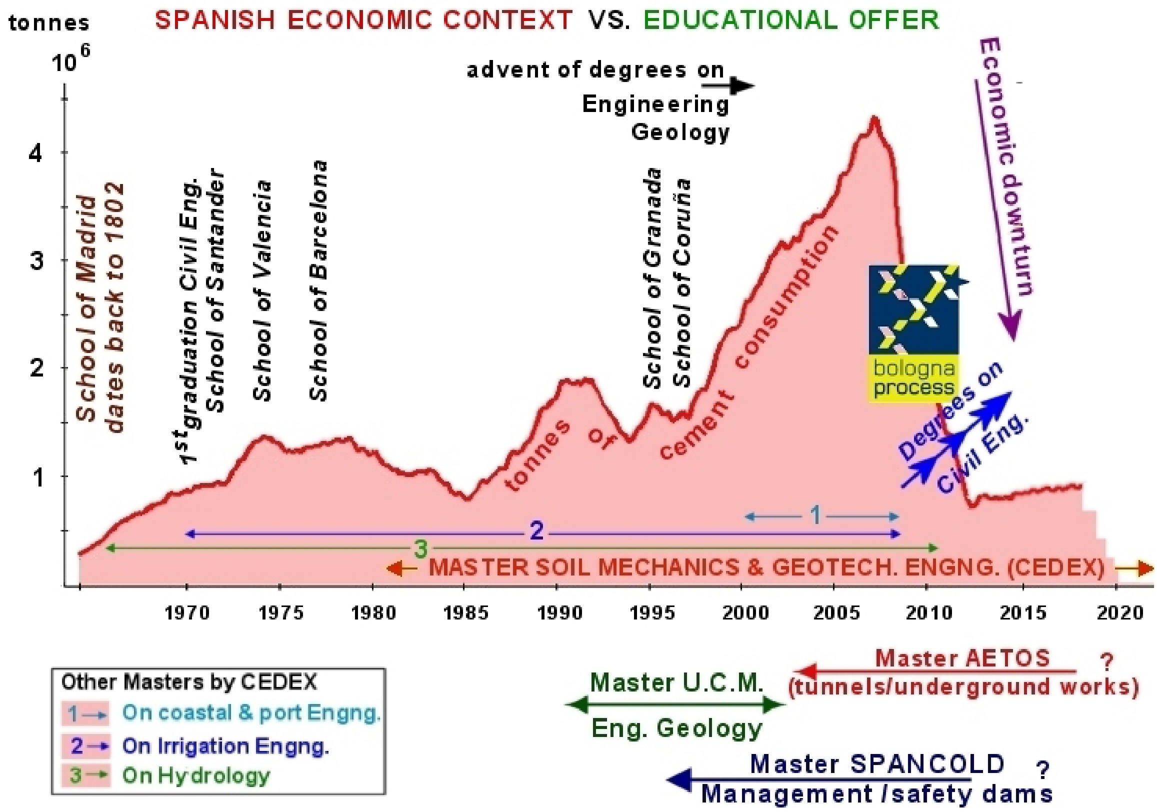

Figure 5. A snapshot of the Spanish education offerings over the last decades in relation to the economic context

5 Conclusion

Despite the costly resources required (hence, the advantageous position of public service), in the authors' experience, onsite learning with sound syllabus with varied lecturers, an international environment where the students are at ease but a bit under pressure by weekly assignments, leads to success. Furthermore, heterogeneity among peers (ages, prospects, background, countries, degrees, etc…) , in a global context, is an unpaired source of learning that is taken in naturally by sharing more than 5 months of hard work. The variety of affiliations of the lecturers is one of the key factors for the success of the Master, as it provides the students with both theoretical background and applicability to the everyday professional work.

Finally, as technical writings in Spanish are strongly promoted from the academic board as a means of counterbalance the unnecessary invasion of anglicisms, the authors perceive that the terminology among the Spanish-spoken community have been strengthen.

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The authors are deeply grateful to all the current and past lecturers and organisations that eagerly contribute to this long-lasting project. The Master makes America and Europe seem to be closer than it looks. Finally, the alumni, currently colleagues, are thankfully acknowledged for their suggestions, engagement, and the labour of diffusion of knowledge.

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Authors' bios

Fernando Pardo de Santayana Carrillo, Laboratorio de Geotecnia - CEDEX, Spain

Ph.D. in Civil Engineering by the Universidad Politécnica of Madrid, Spain (1992); Master of Science by the University of California at Berkeley, USA, in Geotechnical Engineering (1985). Joined the Geotechnical Laboratory of CEDEX (Research Centre of the Spanish Ministry of Transports) in 1986, where he carried out many diverse research and technical assistance works and studies, related to geotechnical problems of roads, use of marginal materials, development and standardization of geotechnical tests, and pathology of foundations. He has been researcher at the Laboratório Nacional de Engenharia Civil of Lisbon, Portugal, where he worked from 1995 to 2006 on issues related to geotechnical engineering of earth and rockfill dams, sanitary landfills and soft soils deposits. He leads the Geotechnical Laboratory of CEDEX, since 2006; he is Director and Professor of the Master of Soil Mechanics and Geotechnical Engineering organized every year by CEDEX and UNED, since 2007; he is President of the Spanish Society for Soil Mechanics and Geotechnical Engineering (SEMSIG), since 2014.

Enrique Asanza, Laboratorio de Geotecnia - CEDEX, Spain

Dr. Asanza was appointed Geotechnical Engineer at CEDEX (Research Center attached to the Transportation and Environment Ministries) in 2007, where he has developed most of his research career and institutional consultancy (environmental & coastal geotechnics and port infrastructures). At present, Dr. Asanza is responsible for the Applied Geotechnics Department, providing support and decision-making for large, disputed or singular projects promoted both by the National Port Authority and by several divisions attached to the two Ministries. In 2012 he joined the Civil Engineering School of Universidad Politécnica de Madrid as an associate lecturer, after having served as lecturer at Universidad Alfonso X El Sabio. At present, he is one of the coordinators and a lecturer of the long-standing International Master on Soil Mechanics (CEDEX), which receives students mainly from Spanish-speaking countries. In 2014, Dr. Asanza was given a 3-month paid leave following an invitation as Visiting Scholar to the Particulate Media Research Laboratory at GeorgiaTech (Atlanta, U.S.A.).

Juan Antonio Díez Torres, Laboratorio de Geotecnia - CEDEX, Spain

Degree in Geological Sciences from the University of Salamanca with the qualification of Extraordinary Award and Master in Geological Engineering from the Complutense University of Madrid. At the University of Salamanca he defended his undergraduate thesis related to the genesis and mineralogy of clays in the Douro Basin and collaborated on different research projects on the behavior of fibrous clay minerals and on the alteration of the Artistic Historical Heritage, completing his training at the Consiglio Nazionale delle Richerche (CNR) of the University of Florence. In 1991 he entered the Geotechnical Laboratory of CEDEX, and since then he has participated in numerous studies and projects on geological and geotechnical pathology related to Civil Engineering: ports, dams, building, communication routes, etc., having published and presented the most relevant conclusions in different national and international journals and congresses. He is representative of CEDEX at the Spanish Society of Rock Mechanics and the Geological Society of Spain, and coordinator of the International Master of Soil Mechanics and Geotechnical Engineering jointly organized by CEDEX and UNED.

Mauro Muñiz-Menéndez, Laboratorio de Geotecnia - CEDEX, Spain

Dr. Mauro Muñiz-Menéndez is a program director at the Geotechnical Laboratory of CEDEX in Madrid (Spain), where he is responsible for the geotechnical laboratory testing in soils and rocks. He holds a bachelor degree in Geology from the University of Oviedo (Spain) and a Master degree in Engineering Geology from the Complutense University of Madrid. He obtained his Ph.D. degree at the same university. He also attended the CEDEX's Master Course in Soil Mechanics and Geotechnical Engineering where he is currently a member of the faculty. His research interests are focused mainly in rock mechanics and laboratory geotechnical testing, and he is a member of several standards committees in these fields. He is the General Secretary of the Spanish Society for Rock Mechanics (SEMR) and a member of the board of the Spanish Society for Soil Mechanics (SEMSIG).

Let's Bring into the Classroom the Reality of Estimating Soil-Engineering Properties

A.D. Platis[1], V.E. Dimitriadi[2] & K.T. Malliou[1]

[1]*Geoconsult Ltd., Athens, Greece*
aplatis@geoconsult.gr, komalliou@geoconsult.gr

[2]*Edinburgh Napier University, Scotland, UK*
V.Dimitriadi@napier.ac.uk

ABSTRACT: Understanding the geotechnical conditions at a project site is of fundamental importance in making informed decisions and shaping optimum engineering solutions. This knowledge mainly covers the determination of the soil stratigraphy and the evaluation of a representative set of design soil properties. While the first is typically explored through the drilling of boreholes and is performed on site, the second aspect is the outcome of in-situ observations and tests and laboratory work, which typically reveals the high variability of the soil. This soil variability however is not normally perceived by young geotechnical engineering graduates, who are used to dealing with uniform soil layers in terms of composition and behaviour during their academic studies. This often leads to frustration and poor performance in their initial professional steps. To that end, the present paper has the ambition to shed some light into the intricate task of soil characterisation and bring into the classroom tangible examples of how the soil non-uniformity is tackled in the professional arena, using as an example the soil properties pertinent to consolidation settlement.

Keywords: site investigation, laboratory testing, geotechnical education, educational material

1 Introduction

A key component in geotechnical practice builds upon evaluating the design parameters of the soil profile at hand, which is based on the characterisation of the encountered layers, acquisition of soil samples and execution of laboratory testing. The specific geotechnical engineering attribute is eloquently communicated in the 1st John Burland Lecture by Atkinson (2016), who stated that 'first-degree graduates with a geological map and memoir, some tubes of soil from the site, a pencil and a paper, should – at a minimum – be able to produce safe and serviceable designs for simple foundations and slopes'. More specifically, Atkinson (2016) describes a suite of three basic tasks that young geotechnical engineers should be able to deliver, namely: (i) model the ground, (ii) evaluate the design parameters and (iii) design simple slopes and foundations. Regarding the design of simple slopes and foundations, it is estimated that most geotechnical graduates will be sufficiently proficient, as opposed to evaluating design soil parameters. The reason behind this is that soil parameters are typically the input information in most worked examples and exercises, which are found in geotechnical engineering textbooks. As a result, students have limited opportunities to practice their skills in determining design soil properties.

Given the above, most young geotechnical engineers generally lack the skills to determine design soil properties and do not perform adequately in related tasks. In many cases, they are even astonished to discover that real soil conditions exhibit a high degree of variability, which needs to be reflected into a unique set of soil property values. In the above context, the question addressed in the present paper concerns the inclusion of actual site investigation and laboratory data –which are normally used for the estimation of design soil properties– in geotechnical education.

To achieve this objective, the first section of the paper compiles and presents information from the site investigation and in situ and laboratory testing from two actual projects in Greece. The first project is located in the island of Corfu (Geoconsult, 1999b) and the second in Nea Karvali, Kavala (Geoconsult, 1999a), as indicated in Figure 1. The criteria for selecting the two projects were (i) the uniformity of the encountered soil profile, (ii) the availability of field and laboratory data and (iii) the availability of during and/or post-construction monitoring data. Monitoring data are particularly important, as they allow the back-calculation of some key soil properties for both projects, as well as a comparison between the back-calculated values and the ones estimated from the in situ and laboratory tests. This comparison is further extended to include typical values from the literature aiming to provide a more complete overview of the possible range of variation of the soil properties under examination. This paper focuses exclusively on the soil properties pertinent to consolidation settlement and their evolution.

The purpose of the above task is to (i) familiarise students with the soil properties that are typically required in the design of different projects and how those are determined, (ii) highlight the potential and (expected) scatter in the obtained values and (iii) showcase how the obtained in situ and laboratory values compare against the 'real' values (based on the back-analysis results) and 'typical' values (based on the literature). Going a step further, the paper also explores the potential development of suitable educational material, which can be incorporated in curriculum design, so that students can experience and appraise the practical aspects of their academic education.

Figure 1. The locations of the selected projects

2 Extension of the apron area of Corfu Airport

2.1 General information of the project

The location of the site is at the South part of the Corfu Airport 'Ioannis Kapodistrias' in the town of Corfu. The project area was flat and swampy with the lagoon water depth ranging between 0.05 m to 0.30 m. The main construction activities planned in the area of the project included:

- An extension towards the South of the apron area with dimensions 325.5 m×200 m.
- Ground supplies area with dimensions 40 m×162 m.
- New connecting taxiway of total length of 623 m at the South-West end of the extension of the apron.
- A 12 m wide service road, parallel to the East boundary of the extension of the parking area.

2.2 Site investigation and laboratory tests programme

The site investigation programme for the airport extension included 4 exploratory boreholes of depth equal to 15.22-24.30 m, and 18 CPT of depth 6.00-24.30 m in the area of the planned extension of the apron. CPTs provided information on the cone resistance (q_c – MPa), local skin friction (f_s – MPa), friction ratio (FR = f_s/q_c – %), soil type and generated excess pore pressure (u – MPa, in the tests with piezocone). Based on the retrieved soil samples a series of laboratory tests were carried out. The type of tests was adjusted to the nature of the soil, the method of sampling and the scope of the investigation. Classification tests as well as physical and mechanical properties tests were carried out on typical samples from the boreholes. The following laboratory tests were performed, with the number of them included in parentheses: determination of water content (22), specific gravity (22), unit weight (14), Atterberg limits (22), sieve analyses (22), hydrometer tests (22), oedometer tests (11), unconfined compression tests (7) and unconsolidated undrained (UU) triaxial compression tests (15).

Based on the results of the geotechnical investigation it was possible to trace the soil stratigraphy in the area of the planned extension. A simplified yet representative design soil profile is presented in Figure 2 and a brief description of each soil layer is provided below:

- Layer [1]: Very soft to soft CLAY of medium to high plasticity (CL-CH), turning deeper to firm and then to stiff clay. The thickness of this layer was highly variable, ranging between 2-17 m.
- Layer [2]: A layer of loose to medium dense SAND and SILT (SM) to organic SILT (OL) (layer [1b] of the original geotechnical investigation), which was at some places encountered as a lens within layer [1] and at other places between layers [1] and [3].
- Layer [3]: Stiff to very stiff CLAY of medium plasticity (CL) (layer [1a] of the original geotechnical investigation).
- Layer [4]: Very stiff to hard CLAY of medium plasticity (CL) (MARLY BEDROCK).

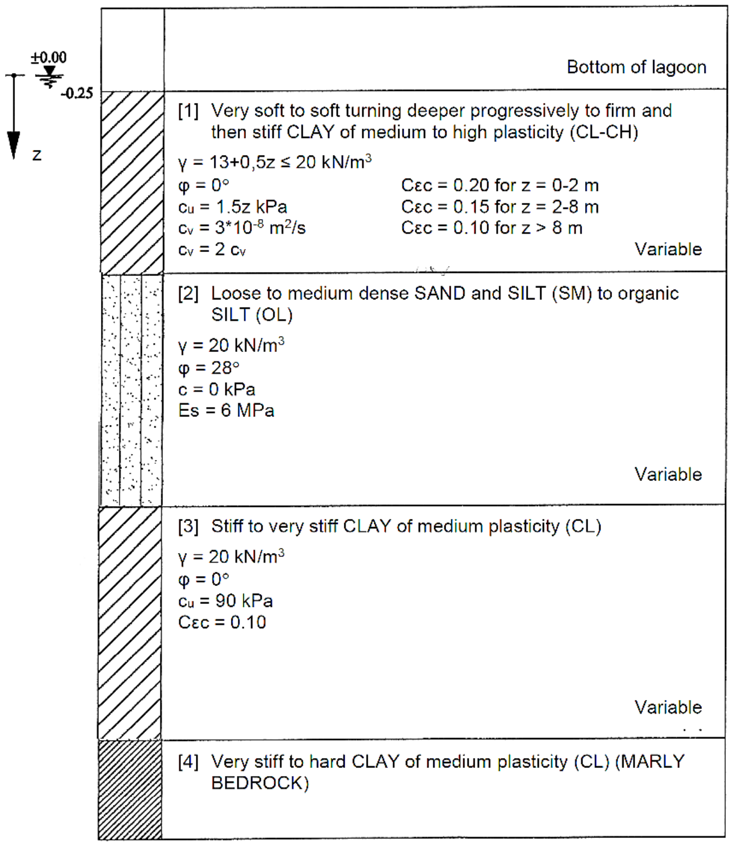

Figure 2. Design soil profile at the Corfu International Airport

2.3 Selection of design properties

The evaluation of the data obtained from the site investigation led to the determination of the design soil parameters, which are included in Figure 2. Relevant graphs and tables of the geotechnical investigation are available as EXCEL files (see Corfu Data, Karvali Data) in http://www.geoconsult.gr/en/publications/. As already mentioned, the focus herein is on the soil properties that most affected the design process concerning consolidation settlement. Due to the variability in thickness (3-17 m) and in consistency (very soft to soft) of clay layer [1], it was concluded that it would be the controlling layer in the geotechnical design of the project. Its compressibility was expected to lead to –uneven– large settlements, which would develop slowly. Moreover, the development of settlements was expected to be spatially affected by the intermittent presence of the intermediate drainage layer (layer [2]).

For the calculation of the expected settlements, the Compression Index (Cc) was estimated from oedometer test results and was found to vary between 0.134 and 0.879 with an average value of 0.359. The Compression Ratio (CR), designated as Cεc in Figure 2, was consequently computed as the ratio of $Cc/(1+e_o)$, where e_o denotes the initial void ratio. This computation provided the variation of CR with depth, which was approximated with the following design values of CR (see also Figure 3):

- CR = 0.20 for z = 0-2 m
- CR = 0.15 for z = 2-8 m
- CR = 0.10 for z > 8 m, (z counting from ±0.00 m)

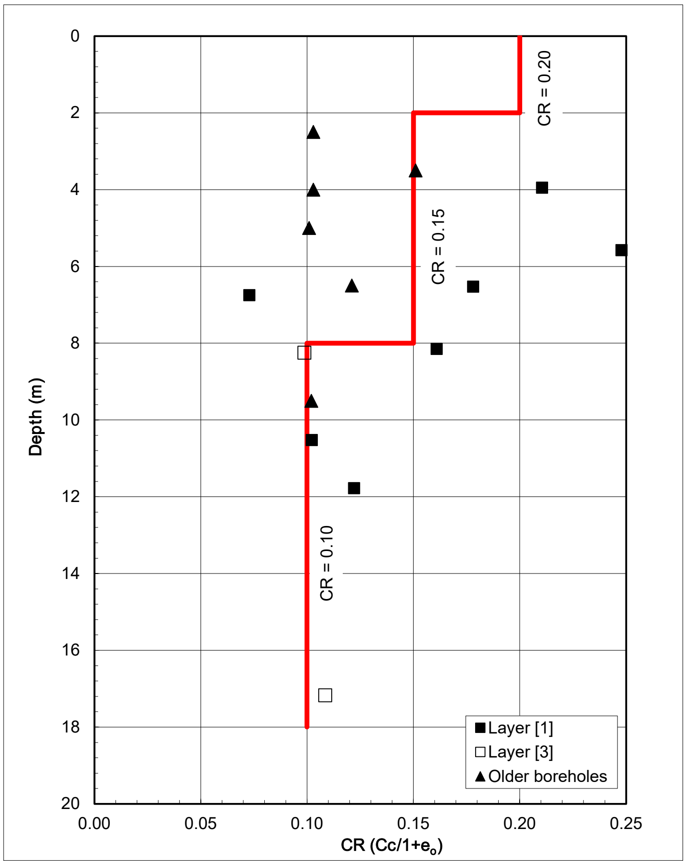

Figure 3. Distribution of CR with depth and design curve (in red)

To obtain a better understanding of the compressibility potential of layers [1] and [3], the compression index Cc values obtained from oedometer laboratory tests are compared with typical values from the literature, which are summarized in Table 1. Using the values in Table 1 and an average project value of LL equal to LL = 42%, gives the Cc values plotted in Figure 4. It is observed that the measured values of Cc in the laboratory (Cc = 0.13 – 0.88, with an average value Cc = 0.36) compare well with the values proposed by literature. What is important to note from Figure 4 is the high variability of the reported values in the literature, which come from different clays around the world, and highlight the need of site-specific laboratory tests.

2.4 The design challenge: Consolidation and settlement acceleration methods

From the relevant geotechnical calculations (Geoconsult, 1999b) the expected primary consolidation settlements for embankments bearing directly on the bottom of the lagoon were estimated between 600-1100 mm. Moreover, the time required for the completion of consolidation was estimated to be of the order of several decades. The expected settlement magnitude along with the non-uniform accumulation pattern and the required consolidation time would pose a significant hazard upon the structural integrity of the planned works. Given the above challenges, it was decided to adopt a ground improvement method, which would accelerate consolidation and would lead to the completion of most of the expected primary consolidation settlements prior to the construction of the pavement. In addition to that, the ground improvement method should also reduce the anticipated long-term secondary compression settlements due to the high plasticity and high organic content of the soft clay layer.

The adopted soil improvement method consisted of preloading in combination with the installation of stone columns, which would act both as vertical drains, for the acceleration of pore pressure dissipation, and as reinforcing elements. The stone columns were 0.70 m in diameter and extended within the upper very soft to soft clayey layer [1] to a depth ranging between 6.00-15.00 m. Their axial distance varied between 2.00-4.50 m. Preloading was performed with an embankment at least 1.50 m higher than the final pavement level, in order to reduce long term secondary compression settlements and further accelerate the completion of expected settlements.

Table 1. Indicative values of compression index Cc

Type of soil	Cc	Reference
CL soft clay	0.34	*Kaufmann and Shermann (1964), Louisiana clays, USA*
CH clay of high plasticity	0.84	
CH soft clay with silt layers	0.52	
New York clays	$C_c = 0.009*(LL - 10)$	*Terzaghi and Peck (1967)*
Clays	0.1 – 0.8	*Budhu (2011)*
All clays	$C_c = 0.01*(LL-13)$	*Ameratunga et al. (2016) [from USACE (1990)]*
Clays from Greece and parts of US	$C_c = 0.4*(e_o-0.25)$	*Ameratunga et al. (2016) [from Azzouz et al. (1976)]*
Medium to high plasticity Maroussi clay (CL2-CH)	0.13 (SD = 0.05)	*Tolis et al. (2006)*
Clays from Greece (mostly CL and a few CH)	0.04 – 0.33	*Bardanis and Kavounidis (2001)*

2.5 Comparison of predicted vs observed performance and back-analysis

Following the installation of the stone columns and the construction of the preloading embankment, the area of the project was systematically monitored over a period of 62 months (12/09/02 to 17/10/07). From the monitored area, two locations (denoted herein as A and B) presented the greatest interest regarding the development of the primary consolidation settlements. Location A was in the area of taxiway D, where the thickness of layer [1] ranged between 7.00 – 12.00 m (7.00 – 9.00 m at the location of the settlement monitoring, hence the considered values in the back-analysis) and the stone columns were arranged in a 3.00 x 3.00 m grid. Location B was in the area of an initial trial embankment, where the thickness of layer [1] ranged between 11.00-19.00 m (17.00 m at the location of the settlement monitoring, hence the considered value in the back-analysis) and the stone columns were arranged in a 2.50 x 2.50 m grid (for more details refer to Platis et al., 2010).

Note that the back-analysis of the time evolution of settlements is not presented in the present paper, as it was a very extensive and multi-parametric process, involving not only the coefficient of compressibility c_v, but also the secondary compression rate C_α, and the horizontal coefficient of consolidation c_h. It was therefore decided by the authors to omit this part of the back-analysis, so that the ultimately available educational material is suitable for use in the classroom. Using the data from the monitoring equipment (settlement plates and electric piezometers), back analyses were executed, including, among others, a reassessment of the compression ratio of the clayey layer [1], which mainly contributed to the measured primary consolidation settlements. According to the back analysis, a fluctuation in the obtained CR values was observed. Namely, for Location A, CR ranged between CR = 0.19÷0.21 and for Location B, the obtained value was significantly lower and equal to CR = 0.09.

Due to the above difference in the compressibility of the clayey layer [1] between Locations A and B, the results of the available consolidation laboratory tests were reviewed. This confirmed a differentiation of the layer's compressibility, which increased from the eastern towards the western part of the project area. Therefore, the initial design was re-visited, and settlements were re-evaluated considering the new average values of the CR, i.e. average $CR_{[1]} = 0.20$ for location A and average $CR_{[1]} = 0.10$ for location B. These new design values correspond to Compression Index values equal to Cc = 0.533-0.589 and

0.252, respectively, for an average initial void ratio e_o = 1.803 for location A and e_o = 1.52 for location B. The different values of the Compression Index Cc, namely lab test results, literature values and back-calculated values, are summarized in Figure 4, so that a more comprehensive overview is provided. The main observation from this plot is the significant scatter observed, both in the reported Cc values in the literature (plotted in grey rhombuses), as well as in the values obtained from the laboratory testing programme (plotted in red squares) and the back-calculated ones (in cyan circles). Namely, it is evident that soil formations with similar classification are not necessarily characterised by comparable values of soil properties. Even within the same project, it may be necessary to consider different design soil properties in order to capture the soil response under the same loading conditions. A solid proof of the above statement is the set of back-calculated values of Cc, which further indicate the highly variable nature of one single soil layer.

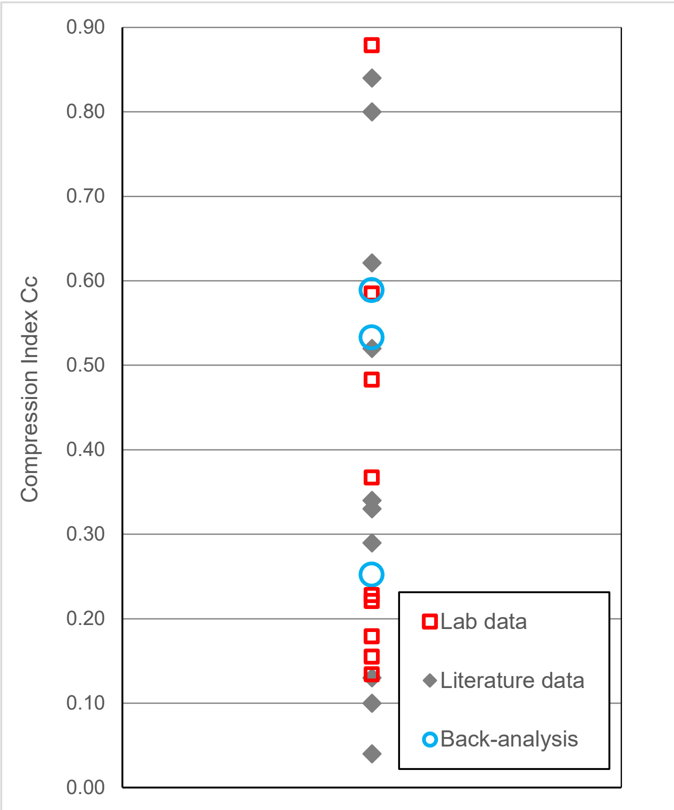

Figure 4. Compression Index values Cc as specified from lab and literature data and the back-analysis

3 Construction of an oil refinery in Nea Karvali, Kavala

3.1 General information on the project

The site selected for the construction of the Kavala Oil Products Terminal of MOTOR OIL HELLAS was located 3 km west of the village of Nea Karvali, in north-Eastern Greece towards the eastern end of Valtos Bay. The site was at a low elevation area (0.00 m to +1.00 m from Mean Sea Level), which had been extensively used as a sand borrow area. The project included the construction of four floating roof fuel tanks, four fixed roof fuel tanks, one water tank, loading gantries, office building and a warehouse, a power substation and a parking area, as well as the offshore construction of an oil unloading jetty. The fuel tanks would have a capacity of 1,000 - 3,000 m^3 and diameter between 12.50 - 22.00 m. The floating roof tanks would be supported by a concrete ring foundation, backfilled by coarse material. The fixed roof tank's steel bottom would rest on a layer of well compacted granular fill. The area of the fuel tanks would be surrounded by a concrete spillage containment wall.

3.2 Site investigation and laboratory tests programme

The site investigation programme included 3 off-shore and 4 on-land exploratory boreholes as well as 12 on-land CPT. Based on the retrieved soil samples a series of laboratory tests were carried out. More specifically, classification tests as well as physical and mechanical properties tests were carried out on typical samples from the boreholes. The following lab tests were executed, with the number of them included in parentheses: sieve analyses (64), hydrometer tests (39), determination of natural water content (64), Atterberg limits (64), specific gravity (39), unit weight (23), oedometer tests (14), unconfined compression tests (15), and unconsolidated undrained (UU) triaxial compression tests (16).

Based on the results of the geotechnical investigation the design soil profile is presented in Figure 5 and a brief description for each soil layer is provided below:

- Layer [1]: Medium dense to dense, fine to medium SAND (SP), turning to silty SAND (SM) with depth.
- Layer [2]: CLAY of medium to high plasticity (CL2-CH) very soft to soft, with organic SILT (OL)
- Layers [3] and [4]: CLAY to sandy CLAY of low to medium plasticity (CL-SC) with thin intercalations of SAND to silty SAND (SM-ML).
- Layer [5]: Coarse grained SAND (SP) to silty SAND, at depths below 24.60 m, in only in one borehole, hence, was not considered in the design soil profile (not shown in Figure 5).

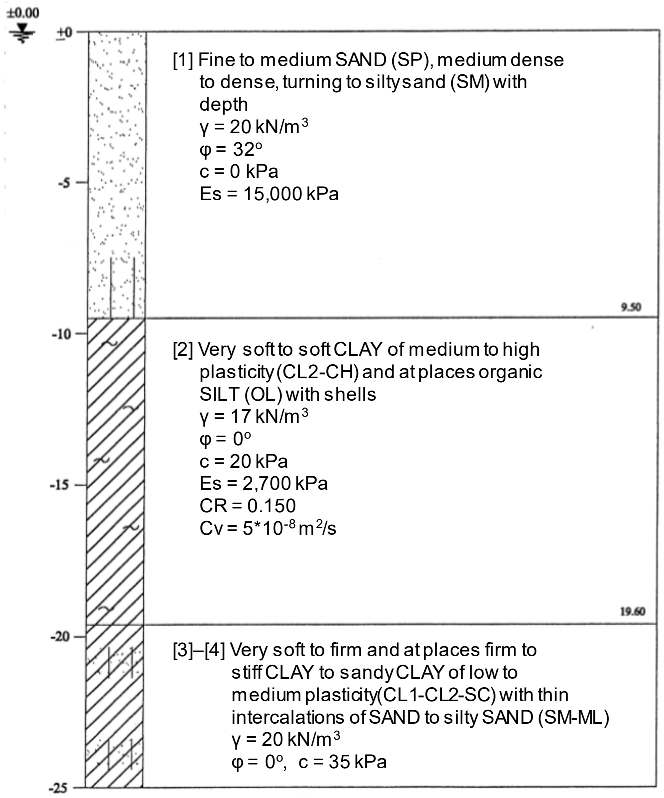

Figure 5. Design soil profile from Nea Karvali

3.3 Selection of design soil properties

Figure 5 also includes the design soil parameters, which were evaluated based on the site investigation programme. An overview of the obtained data from the field and laboratory tests is provided in: http://www.geoconsult.gr/en/publications/ (see Karvali Data). The selection of the Compression Index Cc and the Coefficient of Consolidation c_v is explained herein, as they are linked to the main identified design issues of the project area, and particularly to layer [2].

Regarding the Compression Index (Cc), the (oedometer) laboratory-obtained values range between 0.077 - 0.531, with an average value of Cc = 0.344. Typical values of Cc obtained from the literature are also summarized in Table 1. It is observed that the project values are lower than the range of values reported by Kaufmann and Shermann (1964) for high plasticity clays (Cc = 0.52 - 0.84). Also, the value of Cc estimated by the expression proposed by Terzaghi and Peck (1967), for an average project value of LL equal to LL = 42.7%, is Cc = 0.009*(42.7-10) = 0.29, which falls within the range of the measured Cc values in the laboratory. The Compression Ratio (CR = Cc/(1+e_o)) was estimated from the Cc and corresponding e_o values of each consolidation test and ranged between CR = 0.035 - 0.222.

Regarding the Coefficient of Consolidation c_v, the laboratory-obtained values for c_v range between $2.6*10^{-8}$ – $87.1*10^{-8}$ m^2/s, with an average value of $18.9*10^{-8}$ m^2/s. Typical values of c_v obtained in the literature are summarized in Table 2. The comparison between the design project values and the proposed values in the literature is better appraised in Figure 6. It is observed that on average the best agreement is achieved with the upper values reported by Van Tol et al. (1985) and Wallace and Otto (1964). It is also noted that most of the reported values in the literature are well below c_v = 20 * 10^{-8} m^2/s and therefore closer to the lower range of the design value of c_v = $2.6*10^{-8}$ m^2/s.

For the specific project, the final selection of the design values for CR and c_v was based mainly on the consolidation test results and partly on published literature; the respective design values were CR = 0.15 and c_v = $5*10^{-8}$ m^2/s.

Table 2. Typical values of the Coefficient of Consolidation c_v, proposed in the literature

Type of soil	c_v (m^2/s) $*10^{-8}$	Reference
Soft Blue clay (CL – CH)	1.6 - 26	*Wallace & Otto, 1964*
Organic Silt (OH)	5 - 170	*Lowe et al., 1964*
Chicago City Clay (CL)	8 - 11	*Terzaghi & Peck, 1967*
Sandy silty clay (ML – CL) dredge spoil	5 - 20	*Van Tol et al., 1985*
Organic Silts and Clays (OH)	1 - 10	*Sivakugan, 1990*
San Francisco Bay Mud (CL)	2 - 4	*Budhu, 2011*

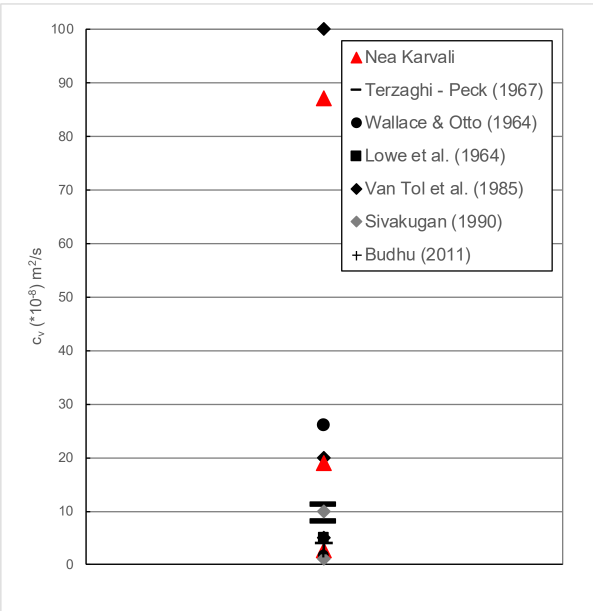

Figure 6. Comparison between design cv values and proposed ranges in the literature

3.4 The design challenge: Consolidation, preloading and prefabricated drains

The main design challenge in this project was the anticipated settlements of the tanks, which, due to their large diameter, also had a considerable depth of influence. According to the performed calculations, for an applied pressure of 100 kPa, settlements varied between 115-190 mm approximately, depending on the tank diameter, with the amount of the anticipated settlements being proportional to the diameter of the tanks. Furthermore, the compressible layer [2] was significantly affected and was expected to contribute the greatest portion of the tank settlements. Even more so, the combination of its considerable thickness (approximately 10 m) and the existence of a single drainage path (pore pressure dissipation would practically take place only through the overlying permeable sandy layer [1]), would mean that settlements were expected to develop slowly. The presence of fine sandy seams could potentially facilitate and accelerate drainage and settlement development, under the condition that they were continuous and extended outside the perimeter of the tanks.

This long-term settlement problem in the tank farm area was proposed to be overcome with preloading and by accelerating pore water pressure dissipation with vertical strip drains. Preloading could be achieved either by constructing an embankment or by the lowering of the water table in the sand or a combination of the two. Following a parametric analysis of 5 triangular drain spacings between 1.50-2.50 m, for selecting the optimum drain arrangement, a 1.50 m equal sided triangular grid was selected based on technical and economical considerations. This solution was combined with the construction of two preloading embankments, one 6.00 m high in the tank farm area and one 7.50 m high in the water tank area, and with a 4.00 m draw-down of the GWL by pumping from 16 water wells surrounding the preloaded areas. The ultimate target of this solution was the completion of primary consolidation within 6 months.

3.5 Comparison of predicted vs observed performance and back-analysis

After the construction of the preloading embankments, monitoring was carried out both for the tank farm area (10 settlement plates (S1-S10)), and the water tank area (2 settlement plates (S11-S12)). The monitoring data from the tank farm area are presented in Figure 7, which include measurements of settlement with time, carried out over a period of 200 days. Location ST-3 refers to the centre of tank TK-3 (S for settlement). These locations were selected (a) because they were close to borehole locations (more accurate soil profile) and (b) because they were situated at different geometrically locations of the preloading embankment. Based on the presented measurements the following observations are made:

- Approximately 7 months after the construction of the embankments, the total settlement was of the order of 461-591 mm (average settlement in the order of 516 mm).
- The rate of settlement was generally faster than expected, which is a common finding in the field (Viggiani, 2019).
- A slight increase in the rate of settlement was observed after approximately 95 days, i.e. at the end of January 2002. This was attributed to an increase of the weight of the embankment due to the unusually high precipitation and snowfall in January.
- The final rate of settlement ranged between 6-10 mm/month, which was within the usual limits given in the literature (of the order of 5-15 mm/month) for terminating preloading.

According to the ground improvement design (Geoconsult Ltd., 2000), the expected consolidation settlement after 7 months due to the preloading embankment in the tank farm area was between 514-534 mm. This range was very comparable to the observed amount of settlement (during the monitoring period), hence no re-evaluation of the Compression Ratio (CR) was performed. On the contrary, the rate of settlement was slightly faster than expected, therefore a back analysis of the coefficient of consolidation c_v was carried out. The results of this back analysis showed that a value of $c_v = 6*10^{-8}$ m^2/s gave a better fit to the actual monitoring data (see Figure 7), which is 20% higher than the design value ($c_v = 5*10^{-8}$ m^2/s).

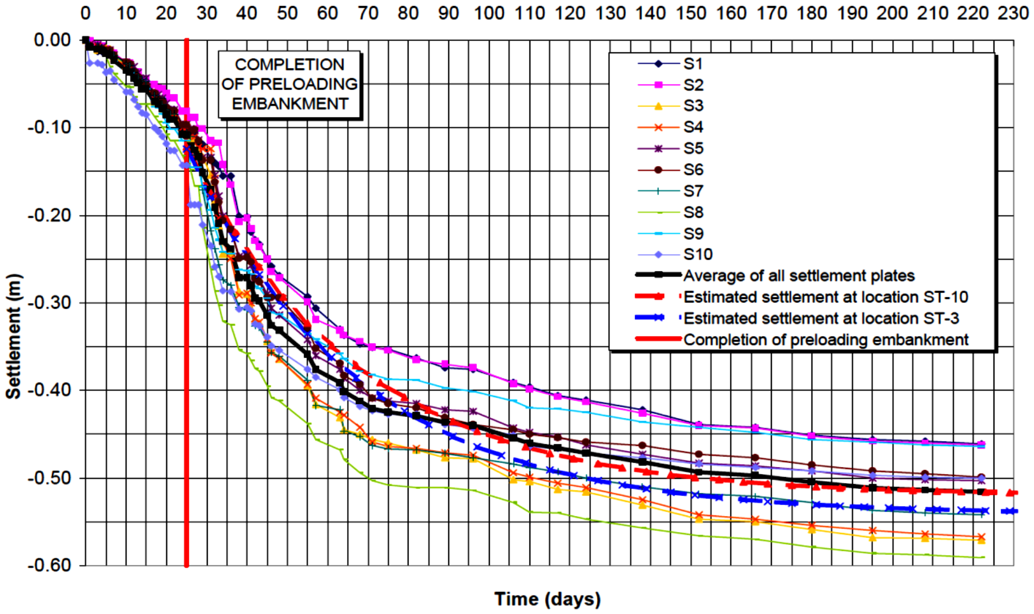

Figure 7. Preloading settlement data from 10 settlement plates as compared to design curves with c_v = $6*10^{-8}$ m²/s

4. Development of educational material and future work

The previously presented material is intended to provide a comprehensive set of geotechnical data from real projects and form the basis for the development of educational material, which can be used in geoengineering education. This project-based learning experience is built around three components, which very much resemble the different stages of a geotechnical project, namely identifying the design soil profile, determining the design soil properties and performing fundamental geotechnical calculations. In the remaining of this section, these three components - each targeting different educational needs - are described, links to the existing material are established and indicative learning outcomes identified. Furthermore, future work considerations are suggested.

The first component focuses on exploring the subsurface conditions and composing the design soil profile. For this purpose, the principles of designing and executing a site investigation and laboratory testing plan need to be explained, in addition to developing skills in the interpretation of the obtained borehole data. In both projects the design soil profiles are already provided (Figures 2 and 5), so the authors propose indicative teaching activities. Namely, relevant background knowledge can be provided in the classroom in the form of technical guidelines as part of a relevant geotechnical engineering module. Also, provided that factual borehole data are available, students can compose their own design soil profile. The purpose of these activities would be to cover the following learning outcomes:

- Evaluating in advance the depth of influence of the planned structures, depending on their geometry and loads, in order to select the desirable depth of the boreholes.
- Considering an appropriate borehole arrangement in order to cover most significant structures (in terms of their magnitudes of loads and their sensitivity in settlements) and get sensible geotechnical sections afterwards, in order to decide the minimum required number of boreholes.
- Conducting a desk study in order to obtain published geological and geotechnical information for the area of the project and deciding the most effective method of drilling and sampling (e.g. rotary drilling with undisturbed samples in soft clays, SPT sampling in sands, wagon drilling or geophysical survey in karst terrain, CPT in deep soft/loose deposits, trial pits and large diameter sampling in filled or dump areas, etc.).
- Preparing a laboratory-testing programme (types of tests carried out depending on the soil type).
- Interpreting borehole data.
- Producing typical geological cross-sections.

The second component is oriented towards interpreting lab and field test data to determine relevant design soil properties prior to any geotechnical design. To this end, the available batch of information from both projects is available to download as both raw lab data, but also organised in tables and graphs showing the range of variation of the soil properties and their distribution with depth. Using the provided material, learning activities should aim in mobilising the students to use the site investigation data and embed the Eurocode 7 (EC-7) framework regarding the selection of 'characteristic' and 'design' soil properties. A comparison can be made between the set of the design values, which were adopted in the projects and the students' choices. The proposed activity targets the following learning outcomes:

- Interpreting field and lab test results
- Appraising the principles of EC-7 in defining design soil properties.

The third component of the proposed educational intervention aligns with the final stage of any project in geotechnical engineering, namely that of design. In this section, students should be given the opportunity to act as design engineers, use the design soil profiles and the selected set of soil properties of the previous stages to shape suitable engineering solutions. It is believed that this activity is better to be limited to the design of a specific structure, such as a shallow foundation (i.e. calculation of settlements, bearing capacity and time required for completion of consolidation when a clay layer is present) so that the various design challenges are covered in depth. With reference to the presented projects, consolidation settlements and consolidation time were the main geotechnical challenges and indicative results are reported considering the mean values of the obtained soil properties. In that context, students can perform their own calculations and explore the sensitivity of their results against selected soil properties. For comparison purposes, the detailed calculations for both projects are available upon communication with the authors. The purpose of this final activity will be to cover the following learning outcomes:

- Calculate settlements and consolidation time for indicative structures
- Investigate the sensitivity of the obtained results against the fluctuation of the selected soil properties (e.g. the change in settlements by adopting higher or lower values of Cc, or thickness of the compressible layer, groundwater table fluctuations)
- Explore ways of improving the original design (i.e. means of accelerating consolidation) and potentially performing a preliminary cost-benefit evaluation.

This last component has multiple benefits as it provides students an opportunity to critically reflect on the significance of the selected soil properties upon the design of civil engineering projects both on qualitative and quantitative terms.

5. Conclusions

In the present paper, the authors have attempted to touch upon the intricate issue of selecting design soil properties, based on the available site investigation reports and lab test data and explore ways of introducing this aspect into the classroom. For that purpose, two projects from Greece were selected, representing the two extremes that one may encounter in practice: one with very uniform layering and soil properties (Nea Karvali) and one with pronounced variability both in stratigraphy and soil properties (Corfu). A database of geotechnical data has been created from these two projects, which can be used as a basis for the development of additional learning activities. The data from the Nea Karvali project could be used for simple soil mechanics calculations, whereas the data from Corfu can be used for more complex soil mechanics calculations, such as sensitivity analyses in terms of strata thickness or soil properties variability, probability of bearing capacity failure estimations, differential settlement estimations, etc.

The authors would like to invite educators in geotechnical engineering to include this material in their classrooms and provide feedback and comments for its further improvement. Additionally, practicing engineers can contribute in extending this database with soil formations from other countries.

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Authors' bios

Athanasios Platis, Geoconsult Ltd, Greece

Athanasios Platis is the Managing Director and Senior Partner of the geotechnical consulting company Geoconsult Ltd since 1992. He obtained a diploma in civil engineering (5-yr degree) from the University of Patras and a M. Eng in Geotechnical Engineering from the University of California at Berkeley. Over the past 33 years he has been involved in most aspects of design and supervision of geotechnical engineering in Greece, the coordination of geotechnical investigations, geotechnical design and consulting, supervision design review and expert advice for various projects, such as harbours and port facilities, renewable energy, highway and railroad projects. He has co-authored many technical notes and conference and journal papers on a variety of topics, as a result of his extensive professional experience. He has a deep interest in the development of innovative resources aiming at training new geotechnical engineers and combining comprehensive theoretical background with practical aspects.

Vasiliki Dimitriadi, Edinburgh Napier University, Scotland, UK

Dr. Vasiliki Dimitriadi is a Lecturer (Assistant Professor) at Edinburgh Napier University, Scotland, UK, who specialises in the field of Geotechnical Engineering. She graduated in civil engineering from National Technical University of Athens (NTUA) (5-yr degree), obtained a M.Sc. degree from University of California Berkeley, USA, and a Ph.D. degree from NTUA. Between 2014 and 2018 she worked as a geotechnical consultant in Athens, Greece, and has obtained significant experience through her involvement in a wide spectrum of civil engineering projects. Most of her research experience focuses on earthquake-induced liquefaction and the response of shallow foundations in a liquefaction regime. Since joining Edinburgh Napier University in 2018, she has further expanded her research interests in ground improvement methods for foundation remediation under static conditions. She is also actively pursuing educational research opportunities, with a focus on project-based learning and is interested in creating opportunities for academia – industry collaborations.

Konstantina Malliou, Geoconsult Ltd, Greece

Konstantina Malliou is a member of the permanent scientific staff of the geotechnical consulting company Geoconsult Ltd and partner since 2013. She graduated in civil engineering from the National Technical University of Athens (NTUA) (5-yr degree). During her employment at Geoconsult Ltd she has been involved in a variety of projects and obtained key qualifications in the interpretation of geotechnical data and the subsequent geotechnical design of various projects, such as power plants, power distribution units, harbours and port facilities, industrial buildings, sanitary landfills, soil improvement. She has been a co-author in several publications in technical and conference papers and is particularly interested in joint initiatives between industry and academia that promote project-based learning.

Graduate Student Perceptions of Mentoring: A Pilot Case Study in the Geotechnical Graduate Student Society at UC Davis

K. Ziotopoulou[1], C. E. Bronner[1] & D. M. Moug[2]

[1]*University of California, Davis, CA, USA*
kziotopoulou@ucdavis.edu, cebronner@ucdavis.edu

[2]*Portland State University, Portland, OR, USA*
dmoug@pdx.edu

ABSTRACT: Although sometimes treated synonymously in graduate school, advisors and mentors have distinct roles. Students require different types of guidance in their development from how to build a professional network to how to handle bias in the workplace to balancing a family and graduate school. As graduate student backgrounds increase in diversity, it is unlikely one individual faculty member will be able to meet all the mentoring needs of a student. This paper explores the practices of a geotechnical graduate student group in the U.S., where the activities of a graduate student organization working in tandem with three research centers provide an array of professional development opportunities, including mentoring experiences. A survey was administered to capture the experiences of graduate students in the organization. Results are presented and summarized, targeted at exploring the types and degrees of mentoring interactions and identifying key contributors to training in different categories. Findings emphasize the role of the advisor but also point out that there is always at least one more resource of mentoring in each category thus pointing out the importance of (a) providing opportunities for interactions and (b) an open culture that promotes them.

Keywords: mentoring, professional development, ladder mentoring, graduate students, survey

1 Introduction

Recently research into mentoring practices for engineering graduate student has increased (e.g. Ahn & Cox, 2016; Fowler, 2017; Pelegrino et al., 2015). Many studies target mentoring practices for underrepresented populations (gender, ethnicity, and race) and international students.

Most graduate programs lack a formalized mentoring structure. However, there are still various resources available to students that enhance their graduate experience, contribute to their success in graduate school and prepare them for successful careers in industry and academia. Numerous questions pertain to how these functions are achieved, the key contributors, how the students perceive them, and how they can be enhanced.

The goal of this paper is to present and analyze results from a pilot study on the impact of the various resources available within one geotechnical graduate program on the mentoring experiences of graduate students. A survey was designed and conducted towards assessing current geotechnical graduate student experience. For the purpose of this survey, mentoring was defined as a professional relationship in which an experienced person (the mentor) assists another (the mentee) in developing specific skills and knowledge that will enhance the less-experienced person's professional and personal growth. This interaction can occur between an advisor and a student, a faculty member and a student, or two students. This paper presents a description of the studied graduate student population and program, followed by an overview of the survey. Selected results are presented and conclusions identify which functions contribute most to enhanced graduate student experiences. The paper concludes with a discussion of future work.

2 Mentoring in Graduate School

Graduate studies serve by definition a dual purpose: deepen technical knowledge and prepare students for the workforce. These functions develop beyond the classroom in ways that are still not strictly formalized. Studies (e.g. Cameron & Woods, 2016) frequently acknowledge that faculty historically enter their profession without specific or formal training in how to train others. Cameron & Woods (2016) point out that as a result, there is a great variety of knowledge and expertise that shapes professional development activities in higher education institutions.

Most universities offer a multitude of professional development resources designed for graduate students that go beyond the technical or thematic training typically provided by the advisor or Principal Investigator. Such resources may be located under programs of the office of graduate studies, centers for international students, and teaching centers. Universities also offer professional development series for future professor workshops (e.g. Professors for the Future program at UC Davis), writing retreats, and work-life-balance workshops. Regardless of how vast the number and types of these resources are, it is usually up to the graduate student to identify and pursue such opportunities. However, graduate students may not know early in the process what they need to be: 1) successful and balanced and 2) better prepared for the workforce (academia or industry). Individual graduate programs often do not include formal mentoring components but they may inform graduate students about available opportunities. Resources for graduate students may be underutilized due to timing/frequency (e.g. too many on-campus events over the duration of one week, the overwhelming barrage of information through which students receive information (e.g. blogs, twitter threads, general online resources etc.), or a lack of priority when these activities are compared to more urgent timelines (e.g. assignments, exams, papers).

The geotechnical group at UC Davis has been steadily growing over the last 10 years and has succeeded in securing funding for two major research centers (the NHERI Centrifuge Facility and the NSF Engineering Research Center for Bio-mediated and Bio-inspired Geotechnics (CBBG)), graduating Ph.D. students that have continued their careers in academia as Assistant Professors, and recruiting and retaining highly motivated and productive graduate students. In this paper, we posit that a key aspect of the group's success is a culture of mentoring and support that runs through the professional, educational, and affective operations involving UC Davis geotechnical faculty and students. Despite anecdotal data supporting our hypothesis, we have had little formal evidence and data. As such, herein we explore the practices of the group wherein a graduate student organization and its activities, alongside with the operations of individual research groups and research centers provide ample opportunities for graduate students and promote an overall open culture such that the graduate students can continuously develop the skillsets necessary to succeed in graduate school and beyond.

3 Graduate Student Development in UC Davis

For the purpose of this work we identify the various sources of mentoring that graduate students can receive beyond the advisor-advisee interactions with their advisors and their research group meetings. In this section sources of graduate student development are summarized and described.

3.1 The Geotechnical Graduate Student Society (GGSS) of UC Davis

In 2007, graduate students in the Civil and Environmental Engineering Department, at the University of California, Davis established the Geotechnical Graduate Student Society (GGSS) at UC Davis, a student-run organization designed to enhance and broaden their technical education through unique educational, professional and social opportunities. The formation of GGSS was the result of discussions amongst faculty, students, and industry practitioners who realized that technical background is only part of what it takes to become a successful practitioner or researcher in geotechnical engineering (Montgomery et al., 2013). The core goal of the student-run GGSS is to promote scholarship, service, leadership, and social networking for the geotechnical group at UC Davis with the intent of fostering collaboration throughout the group and provide opportunities to enhance the education and professional development of its members. To achieve these goals, GGSS sponsors several types of activities including seminars, field trips, outreach events, social events, and the annual Round Table event. All civil engineering graduate students at UC Davis with an emphasis on geotechnical and pavement engineering are automatically admitted to the group. GGSS averages 30 active members each year, in addition to several visiting scholars, postdoctoral students, select undergraduate students and "friends" who participate as honorary members (Montgomery et al., 2013). The board of directors (five annually elected officers and a non-voting faculty advisor) makes all decisions about the group's operations and provides leadership in executing all activities. The group seeks to broadly maximize the graduate experience while focusing on two fronts: (a) enhancing education through connections with professionals outside of UC Davis through seminars, field trips and an annual institute, which is a daylong or longer workshop led by an invited speaker covering topics outside of the geotechnical graduate curriculum, and (b) career development via participation in conferences and other professional events as well as the annual Round Table, a daylong open house where approximately 50 invited professionals engage directly with graduate students who present their research through oral presentations and poster sessions. This event helps students polish their presentation skills and provides a forum for networking and collaboration between geotechnical professionals, faculty and graduate students. Many students have been introduced to their future employers at this event, with about 85 percent of the program's graduates hired by companies/organizations who attend the Round Table. The Round Table event uniquely bridges the academic-industry gap and opens necessary conversations with professional geotechnical engineers to help refine research goals and inspire new projects based on the current needs of the industry (Montgomery et al., 2013).

3.2. Research Centers (CGM / CBBG / UCPRC)

The UC Davis Geotechnical group is the home of the three different research centers described in Table 1. The Center for Geotechnical Modeling (CGM) and the Center for Biomediated and Bioinspired Geotechnics (CBBG) have developed a Ladder Mentoring Model (LMM) for mentoring graduate students in academic environments that does not increase demands on center personnel (Bronner et al., 2018). The LMM combines ideas (or elements) from several existing mentoring models and relies on six core principles. These principles are: (1) providing a sustainable structure with clear expectations, (2) tailoring mentoring to needs of the individual, (3) leveraging resources generously, (4) promoting an inclusive culture, (5) encouraging consistent assessment, and (6) building networks that expand beyond the borders of the institution. Students receive guidance from a variety of mentors with different areas and levels of expertise or experience. Bronner et al. (2018) provide a brief overview of the UC Davis LMM and explain how it is integrated into three critical areas of graduate student development: technical training, professional skills, and educational outreach. This discussion will not be repeated herein for brevity.

Table 1: UC Davis Geotechnical Organizations that provide professional development opportunities for graduate students (after Bronner et al., 2018)

Organization	*Purpose*
CBBG (Center for Bio-mediated and bio-inspired geotechnics)	Transform geotechnical practice by developing technologies that leverage natural biogeochemical processes or leveraging principles/functions/forms from natural analogs (i.e., bio-inspired), resulting in more efficient and sustainable solutions
CGM (Center for Geotechnical Modeling)	Provides access to world-class geotechnical modeling facilities to enable major advances in the ability to predict and improve the performance of soil and soil-structure systems affected by natural hazards
UCPRC (University of California Pavement Research Center)	Dedicated to providing knowledge, the Pavement Research Center uses innovative research and sound engineering principles to improve pavement structures, materials, and technologies.

In addition to training and developing skillsets pertinent to disciplinary topics of each center, students voluntarily participate in outreach activities as well. These activities include providing several tours of the facilities (mainly the CGM) each year for K-12 (kindergarten to 12th grade) student groups including Cub Scouts, summer camps and field trips from local elementary, middle, high schools, and community colleges. The tours are customized based on the audience with a time frame ranging anywhere from two hours to a full day and the group sizes range from 8 to 60 students. These activities are constructive and rewarding for the graduate students and help promote geotechnical engineering to the local community as well as help the graduate students practice communicating their research to a broad range of audiences.

4 Design of Survey

A survey was designed to assess current geotechnical graduate student experience. Survey questions are listed in Table 2; some questions were adaptive based on prior answers. For the purpose of this survey, as previously mentioned, mentoring was defined as a professional relationship in which an experienced person (the mentor) assists another (the mentee) in developing specific skills and knowledge that will enhance the less-experienced person's professional and personal growth. This can occur between an advisor and a student, a non-advisor faculty member and a student, or two students.

The questionnaire objectives were to: (1) collect the demographics of the student study group and their incoming (past affiliations) and desired outcome (target degree) (Q1 to Q5), (2) determine the types and degrees of mentoring interactions they experienced in the program (Q6 to Q11), (3) define the areas in which mentoring occurred (leadership, time management, writing, etc.), (4) identify the engagement with the GGSS and its activities (Q12 to Q20), (5) investigate the perceptions that students have of their mentor/mentee experiences, and lastly (6) solicit their input on future undertakings (Q21 to Q26). A pilot version of the questionnaire was sent to four graduate students to help identify any gaps or issues in the questions. The survey was then deployed (January to March of 2018) to 46 current graduate students. The survey was intentionally not sent to any alumni. As such the study assesses a static status of graduate student perceptions of mentoring and not the development of mentoring opportunities and perceptions through the years.

Table 2. Survey questions and indicative potential answers

Q1. What is your relation to the UC Davis graduate geotechnical department? >> *Potential answer: Current student* **Q2.** What is your expected graduation date? **Q3.** What is the highest-level graduate degree you plan to earn from UC Davis? >> *Potential answer: Post Doc* **Q4.** What is your expected graduation date? **Q5.** Please list your previous institutions i. Undergraduate ii. Undergraduate - if you attended more than one university iii. Masters - if applicable iv. PhD
Q6. Who is/are your advisor(s)? [*Check all that apply*: Advisor(s) Name(s): (Abrahamson, Boulanger, Bronner, Dafalias, DeJong, Harvey, Idriss, Jeremic, Kutter, Lucia, Martinez, Ziotopoulou, other]
Q7. How often do you meet with your advisor? [*check one*: Weekly, Biweekly – every other week, Once a month, As needed]
Q8. How often do you have mentoring interactions with each professor (other than your advisor)? [*all faculty listed and then check one for each faculty*: Never, Rarely, Occasionally, Routinely]
Q9. For each row, choose the resources (column titles) in which you've received the most training. If you've received no training in an area select N/A, if only one applies then only choose one. *Rows: Oral & Written Communication, Team Management / Conflict Resolution, Other Professional Skills, Thesis / Dissertation, Mechanical Workshop Skills, Centrifuge Skills, Numerical Modelling Skills, Other Technical Skills, Navigating Graduate School, Personal Advice, Career Advice, Time Management Skills* *Columns*: *Advisor / Advisors, Other Faculty, Research center (CGM, CBBG) & department staff, Other grad students, Non-department grad resources (e.g. campus wide), GGSS Seminars and Round Table, N/A*
Q10. List all of the people you consider your mentors in the Geotech Program.
Q11. List all of the people you would consider your mentees during your time in the Geotech program.

Q12. Are you a member of the Geotechnical Graduate Student Society (GGSS)? *[Yes / No]*
Q13. If yes in Q12: Have you served in a leadership role at any point? *[Yes / No]*
Q14. About how many years have you been active in GGSS? *[Numeric answer]*
Q15. Approximately how often do you attend the GGSS Seminars? [*check one*: Always, As much as I can (more than half the time), About half the time, Sometimes, Never]
Q16. If you are not active in GGSS, or there have been periods of time where you have been less active, what is/was the primary reason?
Q17. How many Round Table events have you participated in? *(Possible answers 0 to 6+)*
Q18. How many outreach events have you participated in? *(Possible answers 0, 1-2, 3-5, 6-10, 10+)*
Q19. How many GGSS field trips have you participated in so far? *(Possible answers 0,1-2,3-5, 6-10,10+)*
Q20. Broadly speaking, where have you encountered mentoring experiences? Check all that apply. [*Options provided: Graduate program at a different institution, Postgraduate career, REU position, Internship, Undergraduate program*]
Q21. How does your experience as a mentor within the UC Davis geotechnical department compare with other mentoring experiences you have had, including those at other institutions?
Q22. How does your experience as a mentee within the UC Davis geotechnical department compare with other experiences as a mentee you have had, including those at other institutions?
Q23. How can your experience as a mentor at UC Davis be improved? How could have your experience as a mentor at UC Davis been improved?
Q24. How can your experience as a mentee at UC Davis be improved? How could have your experience as a mentee at UC Davis been improved?
Q25. If you were to start a GGSS at a different institution what would be the three ingredients necessary? Please elaborate.
Q26. What is one thing you would change about GGSS?

5 Results and Discussion

This section presents results obtained mainly from the first two sections of the survey (Questions 1 to 20). Results from Questions 21 to 26 which were more descriptive are summarized but are not used to draw any conclusions yet as they are the subject of further research.

5.1 Types and Degrees of Faculty-Student Interactions

A total of 44 graduate students and two post-doctoral researchers participated in this survey and answered the questionnaire. Of the 44 graduate students, 33 were PhD students and 11 were Masters students at the time of the survey. Out of the 46 surveyed people, 22 had undergraduate degrees from an institution outside of the U.S.

Forty-two participants, including the post-doctoral researchers, listed one formal advisor, four listed two co-advisors. The majority of the participants indicated that they met on a weekly basis with their advisors (22 responses), a large minority (18 participants) reported meetings on an as-needed basis, while the remainder reported either biweekly or monthly meetings.

Question 8 was designed to identify if students have mentoring interactions with more faculty than their advisor and if yes how frequently. Nine students reported mentoring interactions only with their own advisors (as reported in Q6) and the average frequency of those interactions was described as “routinely”. The remaining 39 students reported mentoring interactions beyond their advisors. More specifically, seven students reported interactions with one more faculty (“occasionally” average reported frequency), three students with two more faculty (“occasionally” average reported frequency), four students with three more faculty and 21 students with four or more faculty (“rarely / occasionally” average reported frequency). In addition, seven students noted mentoring interactions with staff at experimental facilities (e.g. Center for Geotechnical Modelling CGM or University of California Pavement Research Center UCPRC) as well as with faculty outside of the geotechnical faculty. These interactions ranged from rare to routine with the majority listed as routine. Notably, one student listed another graduate student as an advisor and reported routine interactions with them. Future work will seek to correlate the experiences reported to the types and degrees of interactions reported.

Overall, the results strongly indicate that interactions occur in more than one direction and that students often receive mentoring from three or more faculty members. More interestingly, the mentors are not necessarily the official advisors. It remains to be seen what is the driver behind these relationships, e.g. whether they are intentionally initiated by the advisor encouraging the student to seek mentoring from other faculty or by the student taking initiative towards covering perceived gaps in his/her development. Further research could also clarify whether these mentoring relationships occur more organically in the framework of other pre-existing interactions (in the classroom, during a seminar, during social events etc.) and gradually build up over time.

5.2 Areas and Sources of Mentoring

In Question 9, participants selected their perceived sources of mentoring for a variety of preselected categories that are posited to be important aspects of a students’ research or professional development (e.g. team management, oral and written communication skills, navigating graduate school). Figure 1 presents the results in terms of how many people selected each option per category for nine selected categories of skillsets. Amongst the resources identified, the research center and department staff refer to all the resources and functions available within the operations of CGM, CBBG and UCPRC. This includes either day-to-day operations or meetings (either research or planning). Non-departmental resources refer to any resource or activity available either on- or off- campus but not within the geotechnical group. The GGSS category refers to all the operations of the GGSS (see prior section).

Oral and written communication (Fig. 1a) includes all the skillsets pertaining to disseminating knowledge and communicating science with various audiences. The advisors were reported as the main resource for this skillset with other resources receiving approximately equal weights of about 25% of students. Graduate students are the second most selected resource emphasizing the importance of peer-to-peer mentoring and group meetings in which students practice talks and prepare for disseminating their research.

Team management and conflict resolution (Fig. 1b) includes aspects of human resource management which are valuable for building successful careers in academia and practice. In this category results were slightly more scattered indicating the different practices followed within individual research groups, as well as the key role that research centers can play in setting a paradigm for team management. It is notable that 18 students identified no resources on this topic while no students listed non-departmental resources or GGSS-related resources on this topic.

The thesis / dissertation category (Fig. 1c) encompasses all the aspects that pertain to writing and delivering the thesis (MS students) and dissertation (PhD) students. As expected, the advisors were identified as the primary resource, but the appearance of graduate students as a resource for this category demonstrates the collegial nature developed amongst the students and the peer-to-peer mentoring that has developed amongst a portion of the program’s graduate students.

Centrifuge skills (Fig. 1d) refer to all the aspects of performing centrifuge model testing, a key strength of UC Davis. 30 students left this question unanswered and those were likely the students who did not perform any centrifuge model testing at the CGM facility. In this category, most training comes from the research center and other graduate students with the advisor playing a smaller role in the training. An interesting finding is that almost all the students identified other graduate students as a resource while in some of the cases the advisor was not listed at all. Bronner et al. (2018) present an extensive study on mentoring particularly for research centers and also draw the conclusion that most of the centrifuge skillsets grow with the help of fellow students and the facility itself. Numerical modeling skills (Fig. 1e) refer to all the aspects of performing advanced computational research. The 23 students who left this question unanswered were students who did not perform any computational research. The advisor seems to be the primary resource in this case followed by other faculty indicating the coverage that faculty collegiality can offer to a body of students.

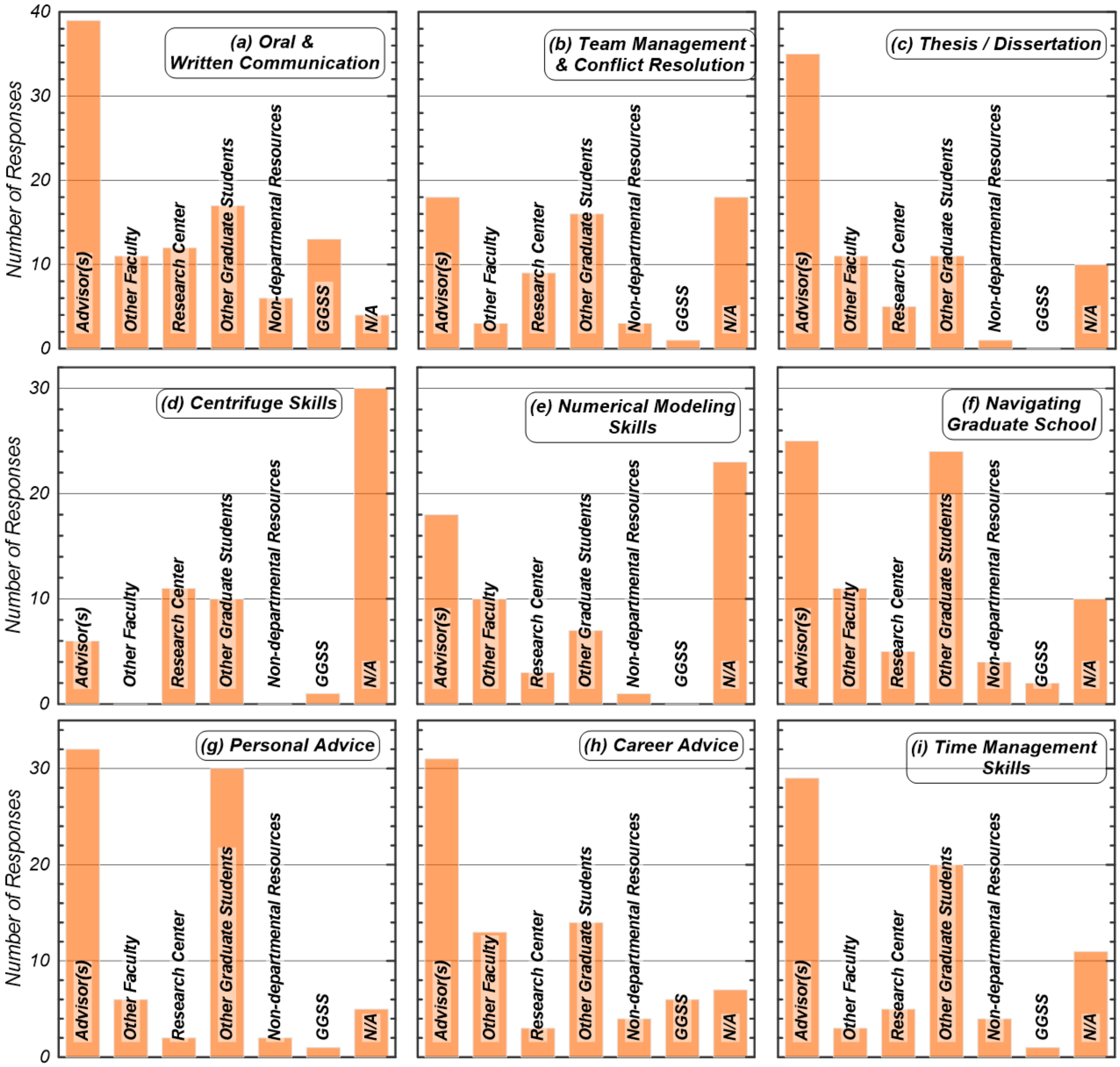

Figure 1. Types and degrees of mentoring interactions with six identified resources of training for nine selected categories of skillsets. Results obtained from Question 9 of survey.

The "navigating graduate school" (Fig. 1f) and "personal advice" (Fig. 1g) categories were listed in order to encompass the skillsets that relate to the life of a graduate student and the components that contribute to its success. In both of these categories the participation of fellow graduate students increased and closely competed with the role of the advisor, indicating that when it comes to more personal conversations, peer-to-peer relationships and potentially friendships can dominate. Interestingly, but not visible in Figs. 1f and 1g, in "navigating graduate school" ten students indicated only other faculty or only other graduate students as their resources. Furthermore, in the resources for personal advice ten students identified their advisor as their sole resource, while 21 identified their advisor in combination with other faculty (6) and predominantly with other graduate students (15). Ten students indicated only other graduate students as their resource for personal advice. The variety of results indicates that students may need sources beyond that of their advisor. More information is needed on which topics students feel comfortable discussion with their advisor, other faculty, and other students. For example, a female student who has a male advisor may seek out a female faculty member to ask them about their experience as an underrepresented group in geotechnical engineering.

The "career advice" category targeted at determining the resources that help students identify career pathways and prepare for those. Advisors stood out here as well as a major contributor and for eleven students the advisor was the sole resource. Twenty-one students identified their advisor in combination with other faculty (12), other graduate students (6), GGSS functions (2), and non-departmental resources (1). Two students indicated only GGSS-related functions as their sole resource and four students identified other faculty or other graduate students as their sole resource. The range of responses requires additional study, perhaps qualitative approaches, to understand the differences in student experience.

Last but not least, the “time management” category (Fig. 1i) aimed at identifying whether and how students learn this skillset from somebody. In this category the advisors closely competed with other graduate students with eight students identifying their advisor as their sole resource, and 21 identifying their advisor in combination with other graduate students (14), other faculty (2), research centers (4), and non-departmental resources (1). Four students identified other faculty or other graduate students as their sole resource.

Overall, the results strongly indicate that the three key resources for training in all categories are the advisors, the graduate students, and the other faculty. Depending on the skillset, the activities within research centers may also be very influential (e.g. centrifuge model testing); it is positive that these tend to be more technical skillsets. GGSS activities like seminars and the Round Table were not perceived as very influential but future research can explore whether these activities instigate any of the mentoring that comes from other resources (e.g. a student presenting during a Round Table event will prepare with the help of his/her advisor and fellow graduate students but will not necessarily list the Round Table as a resource). Another important conclusion is that peer-to-peer relationships between graduate students are key in their professional development and should be cultivated through professional and social functions.

5.3 Engagement with GGSS

The last set of questions (Questions 12 to 19) sought to identify the degree of engagement of students within the GGSS activities, such that correlations can be later drawn between levels of engagement and perceived mentoring relationships or the development of professional skills. Out of the 45 surveyed students, 40 indicated that they were members of GGSS, with 21 out of these 40 having served in a leadership position (president, treasurer, seminar coordinator, social coordinator, fieldtrip coordinator). Twenty students reported always attending GGSS seminars, 11 attended as much as they can, six sometimes attended, and one about half of them, and seven never. The students who indicated not being active in GGSS either always or occasionally admitted that this was mostly due to being busy with work or being overcommitted on other fronts that coincide with the seminar time but wished they could participate more. The average number of Round Table events attended was two across all the students surveyed. This frequency is reasonable given that the event takes place once a year in March and the survey took place between January and February.

Questions 18 and 19 surveyed the participation of students in outreach events and field trips and Figure 2 summarizes the responses in terms of absolute numbers (Fig. 2a and 2c) and normalized numbers (Fig. 2b and 2d) wherein the number of events reported by students was normalized by the number of years each student reported being in the program (Question 14). More than half of the students have participated in at least one outreach event and one field trip but the numbers are definitely not comparable to those of seminar participation. Taking into consideration that there are about three field trips a year and 6 to 8 outreach events a year these numbers are generally encouraging. Future research on the individual responses across the set questions followed by interviews could help identify whether the numbers of Figure 2 correlate with the students’ overall mentoring experience at UC Davis or not.

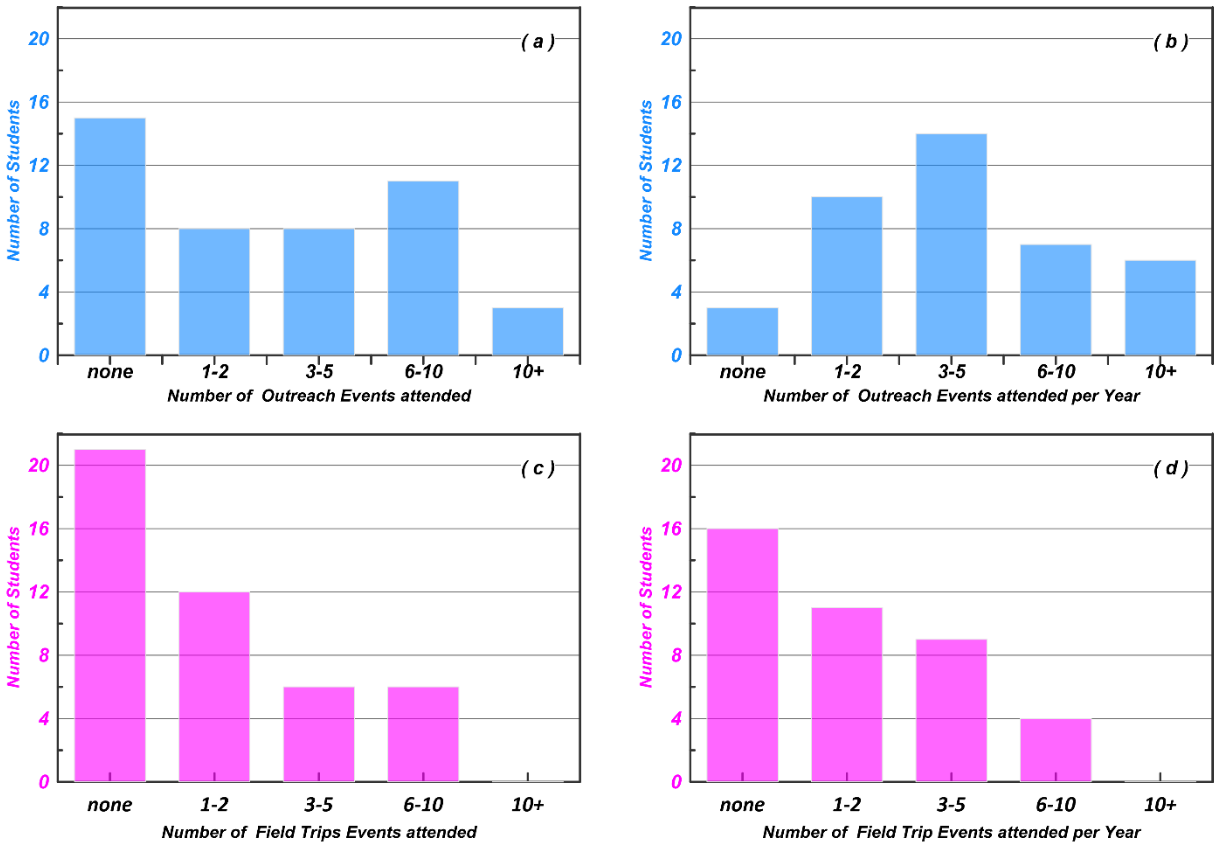

Figure 2. (a) Number of outreach events attended by students who participated in the survey (Questions 18 and 19), (b) number of outreach events attended by students normalized by the number of years of the students at UC Davis, (c) number of field trips attended by students who participated in the survey, (d) number of field trips attended by students normalized by the number of years of the students at UC Davis

5.4. Perceptions of Students

The last set of questions sought to investigate the opinions of students of their experiences and solicit their input for future work and developments within the group. The general sentiment of answers to Questions 21 and 22 was that students appreciate the informal structure of the program and the demeanor of the faculty both of which were characterized as strong contributors to the sense of community. The majority of students also reported that they would appreciate more opportunities to mentor junior students. This emphasizes the importance of Research Experiences for Undergraduates (REU) programs as well as intentional ladder mentoring within research groups. For Question 26 (“What would you change in GGSS?”), the majority of students reported that they would appreciate more interactions with other disciplines as well as more opportunities for interactions across the different research groups.

6 Future Work

Future work can explore various hypotheses about how these relationships initiate and evolve, aiming mostly at identifying key predictors in students’ success through graduate school and enhancing identified gaps. Future work can also address ways of deploying our observations to other graduate student bodies as well as industry. The authors currently distinguish the following as agents of mentoring interactions or of at least developing a fruitful ground for mentoring interactions to flourish in graduate student groups and very likely in industry: shared lab space and shared lab offices, faculty culture and relationships, diverse faculty, weekly seminars, and regular social events. Future work should also explore the opinions of alumni with regards to their experiences and seek to study whether and how practices have evolved through the years and how alumni have applied skills and experiences gained from the graduate program in their careers.

This paper outlined some of the key contributors and functions behind graduate student mentoring. The opportunities offered by a student-run organization can provide a foundation for interactions such that mentoring can more organically develop. The authors consider that graduate programs and faculty in particular should: 1) clearly outline what mentoring is, so that students gradually realize that the graduate student experience goes beyond the advisor-advisee relationship, 2) suggest what growth opportunities students should pursue and where to gain the needed skills, 3) encourage interactions among students in the program through social, outreach and field trips, so that they may develop organic peer mentoring relationships, 4) offer a multitude of opportunities for professional growth (e.g. conference participation), and 5) inform students of resources available beyond the narrow reach of one's research group. The authors recognize that while it is certainly challenging to fit all ideas and resources for graduate student development in one program, offering a multitude of diverse opportunities can gradually encourage students to develop a plan tailored to their own needs and aspirations.

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Authors’ bios

Katerina Ziotopoulou, University of California Davis, USA

Katerina Ziotopoulou is an Assistant Professor in the Civil and Environmental Engineering Department at University of California, Davis. Prior to joining UCD in 2016, she was an Assistant Professor at Virginia Tech for two years. Dr. Ziotopoulou has a Ph.D. in Civil and Environmental Engineering from UC Davis, and a B.S. in Civil Engineering from the National Technical University of Athens, Greece. She teaches undergraduate and graduate geotechnical engineering classes and her research focuses on the performance-based evaluation of liquefaction effects on infrastructure and its mitigation. Dr. Ziotopoulou is also PI/co-PI in projects focusing on understanding mentoring interactions within graduate groups, as well as mentoring international graduate students and women through critical transitions.

Colleen E. Bronner, University of California Davis, USA

Colleen E. Bronner, Ph.D. is an Associate Prof. of Teaching in Civil and Environmental Engineering at UC Davis, where she serves as Department Vice-Chair for Undergraduate Studies. Dr. Bronner has a Ph.D. and B.S. in Environmental Engineering from the University at Buffalo, and a M.S. in Civil Engineering from the UC Berkeley. Her professional interests focus on increasing inclusivity and equity in engineering, development of professional skills in engineering students, and incorporating active-learning styles in undergraduate education. She is the UC Davis Education Lead for a NSF-funded Engineering Research Center, the Center for Bio-mediated, Bio-inspired Geotechnics. Other activities include serving as the faculty advisor of the UC Davis Engineers Without Borders chapter and the newly established UC Davis O-STEM chapter and participation in the American Society of Engineering Education.

Diane Moug, Portland State University

Diane Moug is an Assistant Professor in the Civil and Environmental Engineering department at Portland State University. Prior to joining PSU in 2017, she earned her PhD at the University of California, Davis in geotechnical engineering. She teaches undergraduate and graduate geotechnical engineering classes including Introduction to Geotechnical Engineering, Theoretical and Computational Geomechanics, and Advanced Soil Mechanics. Her research focuses on geotechnical earthquake engineering, particularly subsurface characterization methods and bio-mitigation of liquefaction hazards.

"Educate the Educators:" An International Initiative on Geosynthetics Education

J.G. Zornberg[1], N. Touze[2] & E.M. Palmeira[3]

[1] *The University of Texas at Austin, Austin, Texas, USA*
zornberg@mail.utexas.edu
[2] *Université Paris-Saclay, INRAE, SDAR, Jouy-en-Josas, France*
nathalie.touze@irstea.fr
[3] *University of Brasilia, Brasilia, Brazil*
palmeira@unb.br

ABSTRACT: The International Geosynthetics Society (IGS) has introduced an international educational initiative to facilitate the exposure of geosynthetics, a comparatively new topic within geotechnical engineering education, to undergraduate civil engineering students. A significant hurdle to teaching geosynthetics in university curricula is that geotechnical engineering professors themselves may not have been exposed to the basics of geosynthetics. Consequently, as part of this program, participating civil engineering professors receive fellowships covering their expenses to participate in a workshop consisting of practical demonstrations, pedagogical material and technical documents. Key to the successful implementation of this program has been the participation of and coordination among the International Society, its national chapters and industry leaders who provide the global expertise, local educational framework and practical geotechnical input, respectively.

Keywords: Geosynthetics, Experiential Learning, Instructor Training, Undergraduate Education

1 Introduction

Facing ever increasing technical challenges and a vastly expanded technical base, civil engineering programs are confronted with a dilemma posed by the need to limit the range of material that can be covered while simultaneously meeting the needs of young engineers who should be able to integrate an often fragmented accumulation of analytical tools before confronting real projects as practicing engineers. This dilemma does not mean that new course materials cannot be incorporated into the curriculum. Indeed, new materials can and often must be included to ensure courses remain relevant and are effective. Geosynthetics constitute a comparatively new technology within civil engineering, and it has become essential that geosynthetic education be introduced at the undergraduate level and made broadly available to practicing civil engineers.

This paper documents and evaluates an international training program, "Educate the Educators (EtE)," aimed at providing Geotechnical Engineering university professors with the content and pedagogical tools needed to offer undergraduate civil engineering students ample exposure to geosynthetics. The goal of the EtE program, initiated in 2012 under the umbrella of the International Geosynthetics Society (IGS), is seemingly straightforward: To offer undergraduate civil engineering students a one hour-long exposure class on geosynthetics. Yet the goal, in its reach, is extremely ambitious: To offer this exposure class in fundamental, mandatory courses. The ultimate plan is that by the time she/he graduates, every civil engineering undergraduate student would have received basic exposure to geosynthetics.

As part of this program, civil engineering professors receive fellowships that cover their expenses to participate in a two-day workshop. Practical demonstrations, pedagogical material and instructional documents are provided to participating professors. Beyond covering the one hour-long exposure class on geosynthetics, the EtE program also includes more advanced modules addressing the design of geosynthetics in geotechnical systems, such as retaining walls, embankments, roadways and waste containment. Educational outcomes of programs offered at present are being compiled and indicate a high rate of success in achieving the program goals.

2 Background

Over a half century has passed since geosynthetics were introduced; more than four decades since geosynthetics were widely adopted in separation, stabilization, drainage, wastewater and landfill applications (cushions and liners); and over three decades since the creation of the International Geosynthetics Society (IGS) on 20 November 1983 (Zornberg, 2013) and the publication of the first edition of the landmark textbook *Designing with Geosynthetics* (Koerner, 1986). A variety of geosynthetic products from dozens of manufacturers are available, as exemplified in the annual *Geosynthetics Specifiers Guide* (Industrial Fabrics Association International, 2019). Nonetheless, geosynthetics continue to be regarded as new products by many in the civil engineering industry, and familiarity with geosynthetics or geosynthetic-centric systems and their benefits continues to be limited.

This situation persists, despite (a) the decreased construction costs, the environmental benefits, and the schedule advantages facilitated by geosynthetics and (b) the availability of a wide range of products and a growing number of established design methodologies. The state of geosynthetic education is incongruous with its long history; the development of quality assurance test procedures, and ASTM International, CEN, ISO and other standards; availability of design manuals and training courses; and evidence provided by thousands of successful and varied geosynthetic-inclusive projects.

Why? One answer is education. And how should education on geosynthetics be delivered to capitalize on the benefits and cost savings that could be realized through increased geosynthetic use? The geosynthetics industry includes manufacturers, suppliers, contractors, designers, researchers and academics. However, there is consensus that the focus of the geosynthetics discipline should be on the academics that educate the next generation of engineers.

In its May 2010 meeting, the IGS Council concluded that considerable focus should be placed on geosynthetics at the undergraduate level. It was at this time that the objectives of what became the “Educate the Educators” program were established. The program’s overall goal is to “educate the educator” on how to introduce geosynthetics into undergraduate curricula as the comparatively new, promising technology they represent within civil engineering.

The inaugural “Educate the Educators” program was held in May 2013 in Carlos Paz, Cordoba Province, Argentina (Montoro, 2013). This first event was organized by the Argentinian chapter of the IGS, with the support of the International Geosynthetics Society and in cooperation with the Argentinian Society of Geotechnical Engineering. The event brought together 40 professors from 18 different Argentinian universities, representing 19 different cities across the country, and received sponsorship from industry to cover attendees’ travel costs. Participants were chosen from an initial list of 70 professors interested in the course. The selection criteria involved a professor’s age, experience, maximum academic degree reached and geographic diversity. In this way, middle-aged professors with an MSc or PhD degree were preferred and at least one professor was selected from each university represented in the applicant pool to facilitate the geographic spread of the course.

Since the inaugural program in 2013, 15 subsequent EtE programs have been conducted to date (October 2019) and at least four additional EtE programs are scheduled in the next 12 months. Figure 1 shows the locations of EtE programs completed to date and those planned in the immediate future. As the figure illustrates, 16 EtE programs have already been held in 14 countries across six continents (grouped in four IGS regional committees) and demand for the program has continued increasing. The evolution of the EtE program has been well-balanced geographically, which illustrates the significant interest in geosynthetics education worldwide and the motivation of the IGS chapters.

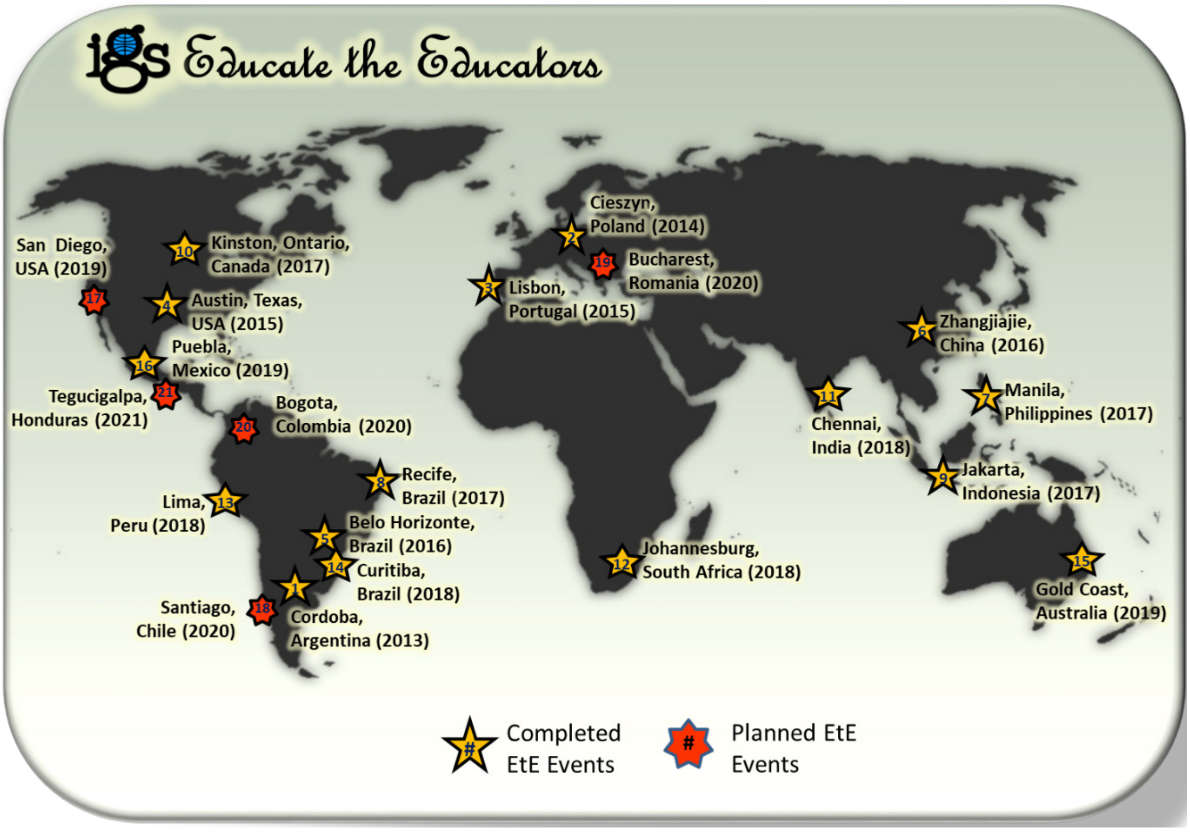

Figure 1. Geographic distribution of "Educate the Educators" programs conducted to date (October 2019) and planned within a 12-month period

3 Structure of the Educate the Educator Program

3.1 Objectives

A growing consensus within the geotechnical community is that focus on education should entail offering basic information on geosynthetics, even if just a single one-hour class within a four-year program, to *all undergraduate* civil engineering students. As a result, all future geotechnical, structural, environmental, transportation, construction and hydraulic engineers will, at the very least, have heard the term "geosynthetics" before they graduate. Providing basic exposure to geosynthetics for all civil engineering undergraduate students is an especially challenging task. Civil engineering programs, facing increasing technical challenges and a vastly expanded technical base, are confronted with a dilemma posed by the need to limit the range of material that can be covered while simultaneously meeting the needs of young engineers. Civil engineering students should be able to integrate an often fragmented accumulation of analytical tools prior to confronting real projects as practicing engineers.

While the overall objective of the EtE program is to "provide basic exposure to geosynthetics for all civil engineering undergraduate students" and focuses on students as the ultimate beneficiaries of the program, the specific objectives of each EtE event focus on the university professor as an attendee of the program. The specific objectives of each EtE event are as follows:

- Provide material for immediate implementation in at least one class on geosynthetics offered to all civil engineering students at the undergraduate level;
- Offer additional information on applications of geosynthetics for implementation in upper level undergraduate courses;
- Offer information that can also be used for advanced classes or graduate courses;
- Assess ways to implement the provided educational material in the classroom;
- Outline the foundation for curricular changes that include the teaching of geosynthetics.

3.2 Philosophy and Logistics

The philosophy of the EtE program is to facilitate the appropriate use of geosynthetics by significantly increasing geosynthetic education and exposure at the undergraduate level. Key to the success of the EtE program has been the framework offered by the IGS as the international learned society, which has not only provided the curriculum, but also facilitated a context for local participation. As previously mentioned, each EtE event involves a partnership between the international society and its national chapter, the local geosynthetics industry and national associations of civil engineering professors.

While significant emphasis has been placed on the development of educational material, equally significant emphasis is placed on its delivery, which should be conducted in-person (i.e. not virtually) to participating university professors. This is an important aspect, as, though it has been tempting to offer the EtE educational material via online platforms, the philosophy of the program is to offer it only in face-to-face forums that facilitate the experiential nature of the technical content. Doing so has allowed EtE educators to engage with learners (i.e. professors) in direct experience and focused reflection to increase knowledge, clarify values and facilitate discussion on curricular issues that often go beyond incorporating geosynthetics content.

In terms of logistics, the IGS provides funding to cover the travel expenses of the program instructors (typically three instructors). The responsibilities of the local IGS Chapter are to coordinate the activities and funding related to the event venue, compilation of educational material (e.g. geosynthetic specimens), promotion of the event, and conception and execution of the application process and selection of professors participating in the event. Lastly, funding for all local travel expenses for participating university professors are provided by the local IGS Chapter along with industry sponsors.

3.3 Educational Content

At the heart of the EtE program is the delivery of an educational program by geotechnical engineering experts to peer geotechnical engineering professors, the core of which was developed by the IGS using significant contributions from experts on each geosynthetic technical area. The actual content of each EtE program is tailored to fit the needs of the local chapter and capitalize as much as possible on the expertise of the geosynthetic experts delivering the program.

The length of previous EtE programs has usually been two days, with at least 16 hours of instructor contact.

The program of an “Educate the Educators” event conducted in Austin, Texas (USA) in 2015 is presented in Figure 2. A review of the program provided in Figure 2 reveals that the main objective of the entire event was to facilitate the incorporation of ONE class (at least) on geosynthetics. This one class was the focus of the entire first quarter of the two-day program offered during this EtE event. The remaining three quarters of the program aimed at providing additional geosynthetics background and motivation to engineering professors, many of whom were exposed to a formal training on geosynthetics technology for the first time at this event. While the remaining modules have varied among different EtE events based on local needs, a typical program includes four modules, which consider four typical undergraduate CE courses, as follows:

- Module 1: A typical “Geotechnical Engineering I” core class
- Module 2: A typical “Geotechnical Design” technical elective class
- Module 3: A typical “Pavement Design” technical elective class
- Module 4: A typical “Environmental Design” technical elective class

The introductory topics (Topics 1, 3, 6 and 9 in Figure 2) are delivered with a focus on didactics and are expected to illustrate the didactics and level of detail anticipated in undergraduate civil engineering courses. The topics identified as ‘advanced’ (Topics 2, 4, 5, 7, 8, 10 and 11 in Figure 2) are delivered at a higher level with a focus on technical content and are expected to illustrate the level of complexity that designers of systems using geosynthetics should achieve. The advanced topics are intended to highlight a few advanced aspects on geosynthetic design in each of the four modules and are not expected to provide a comprehensive treatise on geosynthetics. The discussions shown in Figure 2 are centered on the content, delivery and possible implementation of basic and advanced topics in undergraduate curriculum. Finally, support activities, such as a workshop on identification of geosynthetic products and case histories, are included in the different modules of the program provided by EtE industry sponsors.

SCHEDULE: Tuesday, 28 July

TIME	ACTIVITY
8:30 – 8:45	**Opening:** Welcome and Introductions
8:45 – 9:00	**Discussion:** Teaching geosynthetics in undergraduate classes. Objectives and philosophy of the "Educating the Educators" program
9:00 – 10:00	**Topic 1:** Introductory class on types and functions of geosynthetic materials
10:00 – 10:15	**Discussion:** Incorporating introductory GS class in UG courses
10:15 – 10:30	**Coffee Break**
10:30 – 11:30	**Workshop:** Recognizing different geosynthetic materials
11:30 – 12:30	**Topic 2:** Fundamental properties and related tests on geosynthetic materials
12:30 – 14:00	**Lunch:** Working lunch with group breakouts, networking and sponsor displays
14:00 – 15:00	**Topic 3:** Introductory class on geosynthetics for soil reinforcement applications
15:00 – 15:30	**Discussion:** Incorporating introductory GS class in UG courses
15:30 – 15:50	**Case Histories:** Presented by ETE sponsors
15:50 – 16:10	**Coffee Break**
16:10 – 17:00	**Topic 4:** Advanced topics on geosynthetic-reinforced soil walls
17:00 – 17:50	**Topic 5:** Geosynthetic-reinforced steep slopes
17:50 – 18:00	**Discussion:** Incorporating advanced GS topics in CE curriculum
18:00 – 21:30	**Technical Tour:** A teaching laboratory tour at the TRI facilities followed by dinner at Tres Amigos restaurant

SCHEDULE: Wednesday, 29 July

TIME	ACTIVITY
8:30 – 9:30	**Topic 6:** Introductory class on geosynthetics in roadway systems
9:30 – 10:00	**Discussion:** Incorporating introductory GS class in UG course
10:00 – 10:20	**Case Histories:** Presented by ETE sponsors
10:20 – 10:40	**Coffee Break**
10:40 – 11:30	**Topic 7:** Geosynthetics for stabilization of unpaved roads
11:30 – 12:20	**Topic 8:** Geosynthetics for stabilization of paved roads
12:20 – 12:30	**Discussion:** Incorporating advanced GS topics in CE curriculum
12:30 – 14:00	**Lunch:** Working lunch with group breakouts, networking and sponsor displays
14:00 – 15:00	**Topic 9:** Introductory class on geosynthetics for environmental protection
15:00 – 15:30	**Discussion:** Incorporating introductory GS class in UG courses
15:30 – 15:50	**Case Histories:** Presented by ETE sponsors
15:50 – 16:10	**Coffee Break**
16:10 – 17:00	**Topic 10:** Calculating and minimizing leakage through composite geosynthetic liners
17:00 – 17:50	**Topic 11:** Factors affecting the service life of geosynthetic liners
17:50 – 18:00	**Discussion:** Incorporating advanced GS topics in CE curriculum

- Introductory topic
- Discussion on introductory topic
- Advanced topic
- Discussion on advanced topic
- Support activity

Figure 2. Example of an "Educate the Educators" program, with a focus on introducing geosynthetics in undergraduate civil engineering programs (source: EtE Austin, USA, 2015)

For each topic covered in the program, participating university professors receive course-ready notes (in print and PDF formats), PowerPoint slides, a binder of geosynthetic samples and supporting technical literature/references for each lecture. The lectures are provided in PowerPoint format, and attendees are allowed to use them as initially developed in their own classes or modify them as needed. However, the PowerPoint slides may not be circulated in electronic format to anyone (i.e. their use is exclusively for EtE attendees), nor may they be posted in this format for student access (posting in PDF format is acceptable, though).

4 Importance of the Framework Offered by a Learned Society

4.1 IGS Goals

The IGS is a learned society dedicated to the scientific and engineering development of geotextiles, geomembranes, related products and associated technologies. The core purpose of the IGS is to provide an understanding and promote the appropriate use of geosynthetic technology throughout the world. The vision of the IGS is that geosynthetics be recognized as fundamental to sustainable development by providing technological and engineering solutions to societal and environmental challenges. With this vision, the IGS can make a real contribution to a number of issues currently of concern around the world.

Key to the success of the EtE program has been the framework offered by the IGS, as the international learned society, which has not only provided the curriculum but also facilitated a context for local participation. Accordingly, each EtE event results from a local chapter initiative, which triggers the subsequent involvement of the IGS. The partnership involving the IGS, the local IGS chapter, the local geosynthetics industry, and national associations of civil engineering professors evolves with a clear understanding of the responsibilities of each group.

As previously emphasized, involvement of the local chapter is crucial as it is essential that the EtE course addresses local concerns and needs regarding local applications of geosynthetics as well as local specifications and regulations.

4.2 Against Environmental Injustice

According to the Lancet Commission on Pollution and Health (2017), pollution and pollution-related disease are often reflections of environmental injustice, which is the inequitable exposure of poor, minority, and disenfranchised populations to toxic chemicals, contaminated air and water, unsafe workplaces, and other forms of pollution, and the concomitant disproportionate affliction of these populations by pollution-related diseases, often in violation of their human rights. A core principle of environmental justice is that all people and communities are entitled to equal protection by environmental and public health laws and regulations. In most instances, the poorest people in the world, with the fewest institutional, cultural, governmental, or philanthropic resources to help them, are the most vulnerable to rapidly changing environmental conditions. This is why sharing knowledge through education is fundamental to preventing environmental injustice.

The geosynthetics community continually searches for ways to educate engineering students about geosynthetics and increase their awareness of the usefulness of geosynthetics. In relation to flood prevention and mitigation, Brandl (2010) states that an essential prerequisite for successful mitigation of flood effects is the comprehensive education and training of task forces comprising authorities, organizations, professional groups, and volunteers. Continuing education of clients and construction professionals is also critically important if the benefits of geosynthetics are to be widely dispersed (Dixon et al., 2017). The IGS' chosen approach of teaching educators who will in turn teach students is deemed the most rapid way to spread basics on the appropriate use of geosynthetic technologies. To ensure that environmental justice is achieved and consequently make the knowledge available to all, the IGS provides equal support, including financial support, to all chapters organizing an EtE event. Furthermore, supplemental IGS educational material is made available, for example in the form of a sustainability video, technical leaflets and a glossary of geosynthetics terminology. A series of videos and webinars will also be made available in the future.

5 Case Study – EtE Programs in Brazil

5.1 General Description

As the graphic in Figure 1 illustrates, three EtE courses were delivered in Brazil in 2016, 2017 and 2018. This group of events is described in this paper as a case study to explain the metrics collected on the participants and outcomes of the EtE programs. Figure 3 presents a map of Brazil and the origins of the participants in the three events held in this country. In 2016, the EtE event was held in the city of Belo Horizonte (southeastern region); the 2017 event was held in Recife (northeastern region); and the 2018 event was held in Curitiba (southern region). Despite the country's size and population distribution, a relatively diverse distribution in participants' origins can be observed, with a greater number of attendees coming from the southeastern and southern regions of Brazil. The organization of such courses has had a major impact on the dissemination of geosynthetics among undergraduate students in Brazil, as will be detailed below.

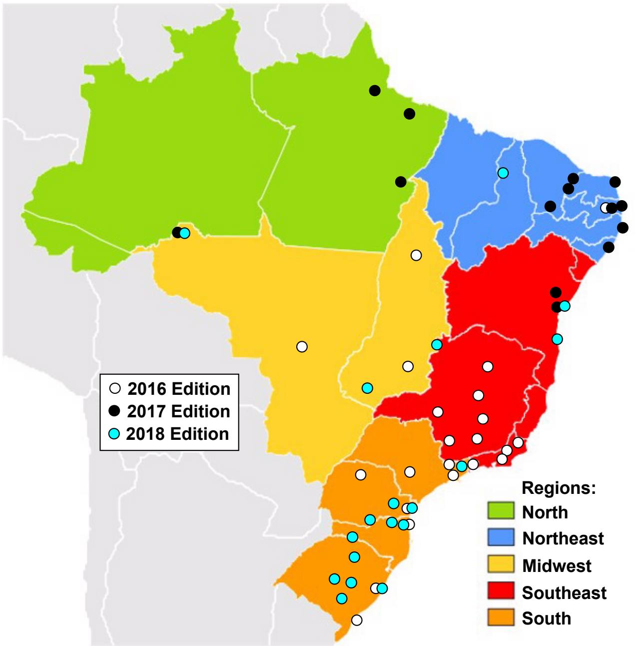

Figure 3. Origins of attendees of EtE courses in Brazil

Consistent with the technical content previously described for the EtE program as a whole, the EtE courses given in Brazil examined different aspects of geosynthetics applications in civil and environmental engineering works. Overall, the following topics were addressed:

- Introduction to the teaching of geosynthetics at the undergraduate level; objectives of the "Educating the Educators" program; course methodology.
- Types and functions of geosynthetics.
- Main applications, relevant properties of geosynthetics and testing.
- Geosynthetics in filtration and drainage.
- Geosynthetic-reinforced walls.
- Geosynthetic-reinforced steep slopes.
- Reinforced embankments on soft soils.
- Pavement reinforcement and restoration.
- Environmental applications of geosynthetics.
- Hydraulic applications of geosynthetics.

Sessions presenting case histories of engineering works involving geosynthetics were held between theoretical classes. Working examples and group activities were also utilized as part of the course.

5.2 Outcomes

An evaluation of the benefits derived from the course can be assessed by interviewing attendees at the end of the event and one year thereafter. Figures 4(a) and 4(b) show evaluations by the attendees of two events in 2016 (27 attendees) and 2018 (29 attendees) in which each item was assigned a grade between 0 and 5. The courses were evaluated very highly by the attendees in relation to quality of learning, quality of course content and overall satisfaction.

As previously stated, the main objective of the "Educating the Educators" program is to provide basic knowledge on geosynthetics to educators, and encourage them to deliver courses and organize activities related to geosynthetics at their academic institutions of origin. Participants were interviewed one year after course completion to evaluate if the main course objectives were achieved. Of the 2016 and 2018 course attendees, 60% and 56%, respectively, responded to a questionnaire aiming at assessing how influential the course was in encouraging them to disseminate the knowledge acquired.

(a)

(b)

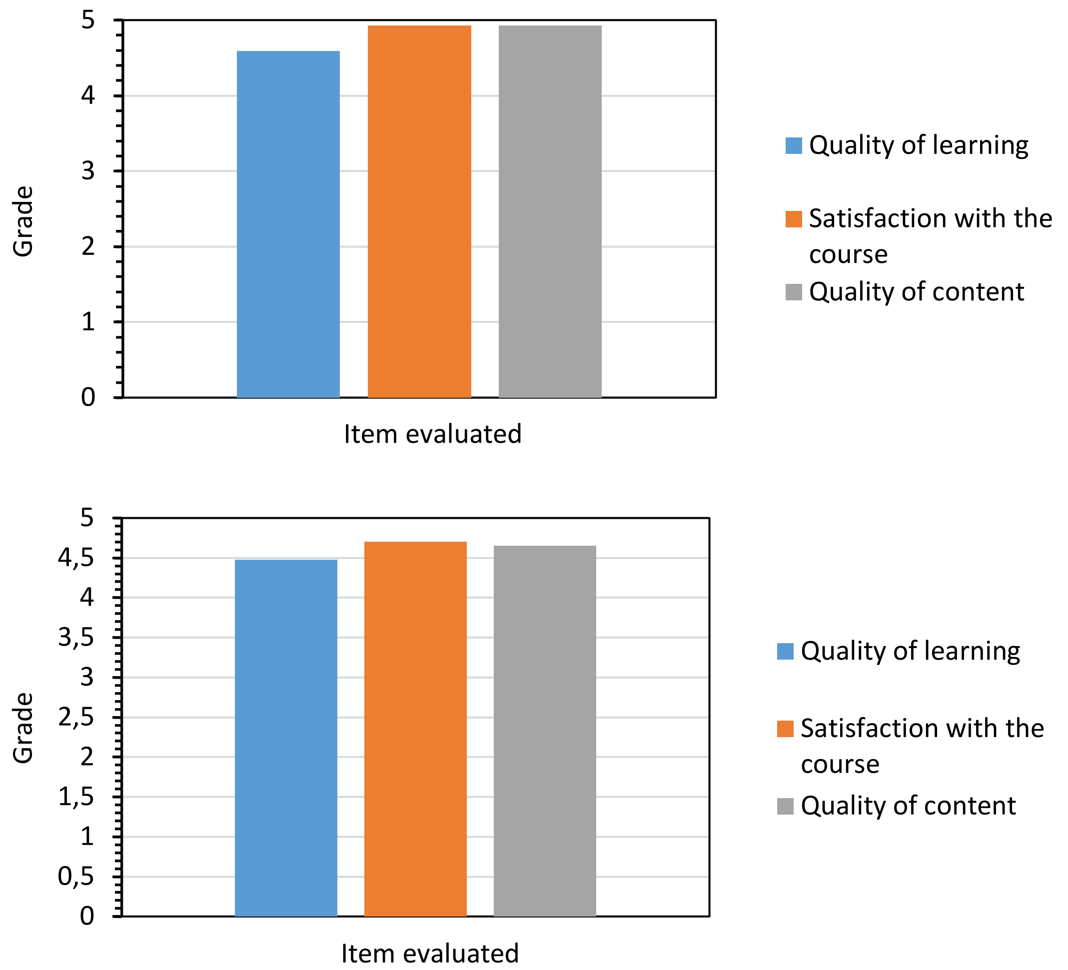

Figure 4. Evaluation of EtE course by attendees: (a) 2016 event; and (b) 2018 event

Figure 5(a) demonstrates that 62% of the 2016 course attendees included geosynthetics themes in existing disciplines in undergraduate courses; 15% created a new course (e.g. a technical elective course) on geosynthetics; 54% included geosynthetics in routine academic events at their institutions; 15% delivered keynote addresses; and 15% offered geosynthetics short-courses. In Figure 5(b), it can be seen that all 2018 course attendees stated that they included geosynthetics in existing disciplines; 33% included geosynthetics in academic events; 11% created a new course on geosynthetics; 11% delivered keynote addresses; and 6% offered geosynthetics short-courses.

Figures 6(a) and 6(b) depict the number of students who enrolled in courses either on or including geosynthetics that were delivered by 2016 and 2018 EtE course attendees at their institutions, respectively. For the 2016 course, 8% of lecturers reported five to 20 students per year; 31% reported 20 to 70 students per year; 23% reported 70 to 150 students per year; and 15% reported over 150 students per year. For the 2018 course, 6% of lecturers reported five to 20 students per year; 50% reported 21 to 70 students per year; 28% reported 71 to 150 students per year; and 17% reported over 150 students per year. Differences between the results of the two EtE courses are likely a consequence of differences in academic conditions, curricula and facilities of the host institutions in different regions of the country.

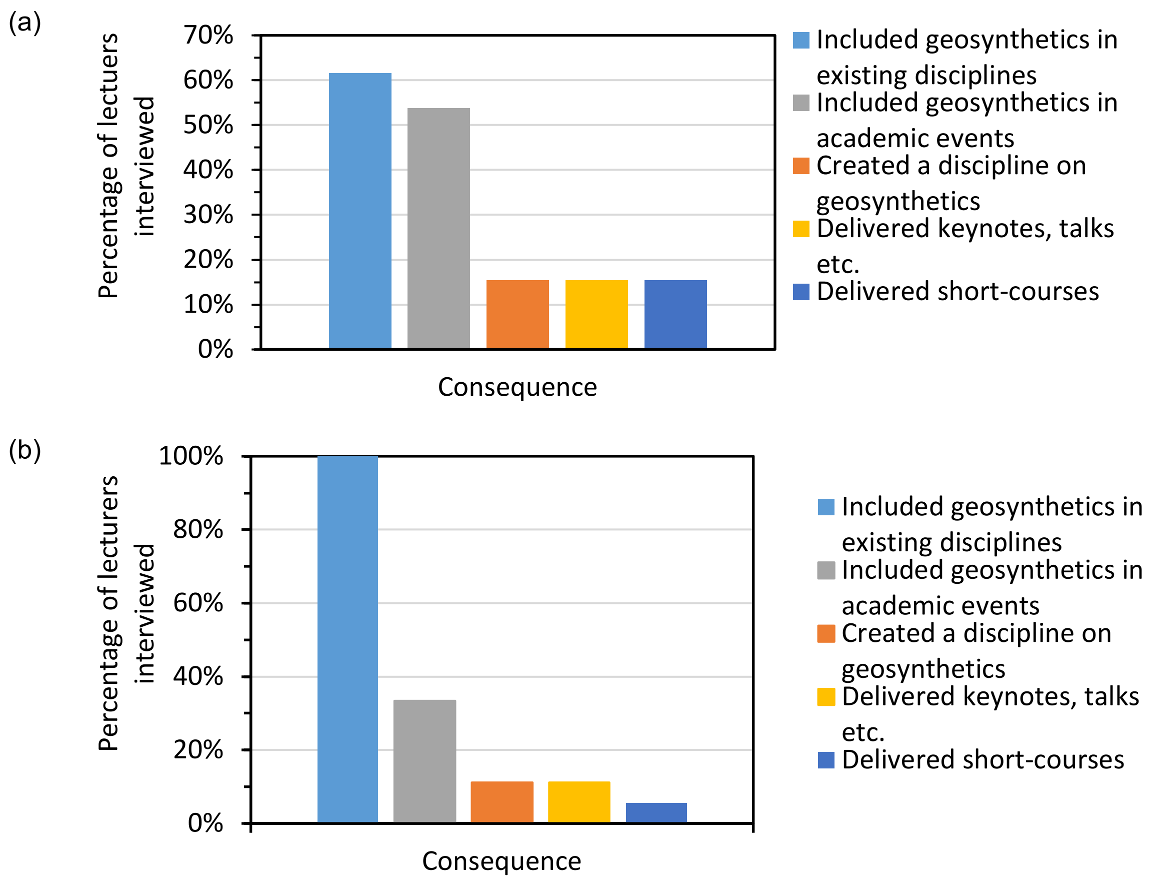

Figure 5. Outcomes of EtE programs conducted in Brazil: (a) 2016 course; and (b) 2018 course

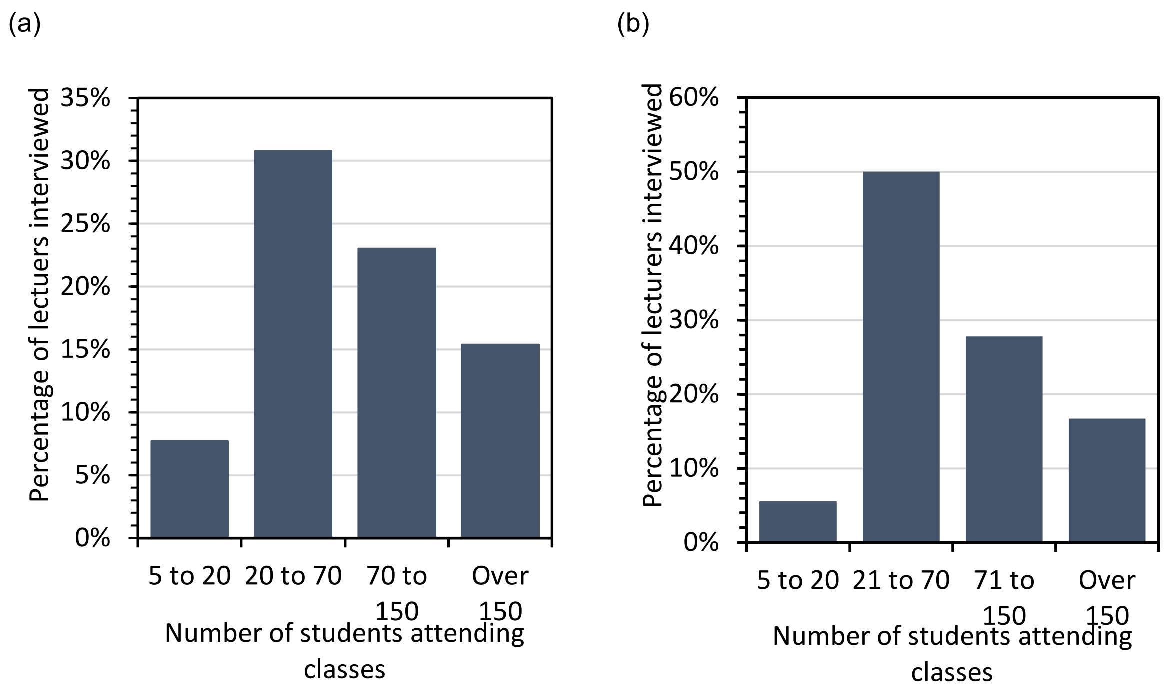

Figure 6. Number of students enrolled in classes delivered by EtE program attendees in Brazil: (a) 2016 course; and (b) 2018 course

The results obtained in the aforementioned surveys of past EtE course attendees in Brazil reveal the effectiveness of these programs in disseminating knowledge on geosynthetics among undergraduate students of civil engineering courses in different parts of Brazil.

6 Conclusions

A program was developed under the umbrella of the IGS to address the need to improve the information available and pedagogical dexterity of undergraduate geotechnical engineering in geosynthetics. With over 15 international “Educate the Educators” programs already completed and a number scheduled in the immediate future, the program has been determined a clear educational success. The results can be quantified as successful objectively, by individual EtE event, with outcomes being compiled over time to assess the implementation of geosynthetics materials at an attendee’s home university, as well as subjectively, by the continued demand for EtE programs across the world.

Overall, the “Educate the Educators” program provides a good example that illustrates the benefits of establishing educational partnerships among relevant stakeholders of a given geotechnical theme to advance educational goals. In this particular case, EtE events have involved collaboration among the International Society, its national chapter, the local geosynthetics industry and national associations of civil engineering professors to successfully advance undergraduate education on geosynthetics.

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Authors' bios

Jorge G. Zornberg, The University of Texas at Austin, USA

Prof. Zornberg has over 30 years' experience in practice and research in geotechnical and geosynthetics engineering. As an engineering consultant, he has been involved in the design of civil, transportation, mining and waste containment infrastructure. He has served as expert witness in numerous litigation and forensic cases. As a researcher, he focuses on transportation geotechnics, geosynthetics, unsaturated soils, expansive clays and environmental geotechnics. From 2010 to 2014, Prof. Zornberg served as president of the International Geosynthetics Society (IGS). He currently chairs the Geosynthetics Technical Committee of the Geo-Institute of ASCE. He has authored over 450 technical publications, edited a number of proceedings and book chapters, and been awarded three patents. Prof. Zornberg has been invited to deliver keynote lectures in over 30 countries around the world. He has also received many prestigious awards, including the Presidential Early Career Award for Scientists and Engineers (PECASE) awarded by the President of the United States.

Nathalie Touze, Université Paris-Saclay, INRAE, SDAR, France

Ennio M. Palmeira, University of Brasilia, Brazil

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